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ChatGPT in Teaching Theory of Computation

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Abstract: The course, theory of computation, appears in many computer science bachelor's degree program curricula. The course examines mathematical proofs based on strictly defined abstract models of computation. Many students who take the course may be accomplished programmers, but they often have limited mathematical training. So, when such students attempt the proofs in the course, they may seek help from online sources, like YouTube, Quora, and StackExchange. As of late 2022, another source is ChatGPT. A concern is that students will use online sources, including ChatGPT, to cheat, to obtain correct answers without learning the material. Unlike other online sources, however, ChatGPT enables students to ask questions about specific proofs in a conversational style. Consequently, it may be possible that ChatGPT may be used to improve student learning, almost like a tutor answering questions about a problem. Moreover, unlike tutors, professors and teaching assistants, ChatGPT is available 24/7/365, without an appointment or waiting in line for other students asking questions of a single person. Further, since ChatGPT is nonhuman, students may feel more comfortable asking "dumb" questions. On the other hand, since ChatGPT is known to hallucinate, perhaps ChatGPT-ing could be even worse than googling. This paper poses questions and compares ChatGPT-3.5 answers with textbook answers known to be correct.

Keywords: theory of computation, ChatGPT, AI, artificial intelligence, LLM, large language model

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Introduction

This research addresses the problem of how to use ChatGPT in the college course, Theory of Computation (TOC). Can ChatGPT be used by students to cheat on homework? Can ChatGPT be used by students as a learning aid? Can ChatGPT be used by teachers as a virtual teaching assistant, to write homework problems and solution sets?

Theory of Computation is important because it is often a required course for computer science undergraduates. It is notoriously complex for students, and challenging for teachers, because it examines mathematical proofs based on strictly defined abstract models of computation. Many students who take the course may be accomplished programmers, but they often have limited mathematical training.

Prior solutions have not always been effective. In the past, when students have gotten stuck attempting to demonstrate proofs in the course, or even just attempting to understand the terminology in the course, they have sought help from online sources, like YouTube, Quora, and StackExchange. Answers from such sources can often be unclear and incorrect. Students continue to search for better sources of accurate information. As of late 2022, another source has been ChatGPT. Some researchers have reported promising results in teaching programming (Yilmaz, 2023). The question is: Would ChatGPT work in learning TOC?

This research attempts to answer such questions. This document reports results from ChatGPT-3.5, given prompts derived from homework exercises and homework problems posed by a major TOC textbook (Sipser, 2013).

Contributions of this paper include (1) concrete documentation of ChatGPT results at a snapshot period in time, late October / early November, 2023, and (2) observations on usability of ChatGPT in a specific course, Theory of Computation, fall 2023. To date, to the best of the author's knowledge, no similar research has been published.

The rest of this paper is organized as follows. The Method section describes the setup and implementation of the experiments. The Results section reports the raw data and summarized quantitative analysis of that data. The Discussion section examines the implications of the results. Finally, the Conclusion section recaps this paper's main points.

Method

Simply put, the author posed questions, prompts, to ChatGPT out of the first three chapters of the textbook (Sipser, 2013). The questions posed were answered in the textbook. Since the textbook is a well-known and authoritative source on TOC, The ChatGPT answers were compared with the textbook answers.

Note that in reproducing these experiments, measuring results presents a range of limitations and challenges. First, ChatGPT as an online tool undergoes frequent modification and enhancement, so it is possible that results might vary even from week to week. The raw data, on which this report is based, is as current as possible, as of this writing, November 1, 2023. By the time the reader reads these words, it is possible the online tool may have been modified to produce slightly different results.

Second, the quality of answers from ChatGPT depends heavily on the sophistication of questions, called "prompts". Efforts have been made to keep the prompt wording as close to the textbook wording as possible. However, it is possible that even slight wording changes might yield different answers from ChatGPT.

The raw data is available at the links in the citations (OpenAI, 2023).

Results

Prompts were prepared from each chapter. Only questions that were fairly easy to type were used as prompts. Many questions contained sophisticated mathematical notation in either the prompt or the answer or both, so those questions were omitted from this study.

Chapter 0: A Simple Proof

ChatGPT-3.5 produced, correctly, a simple proof from Chapter 0 of the textbook (Sipser, 2013). It proved the square root of 2 is irrational. (OpenAI, 2023). [Link](#).

Chapter 1: Proofs About Regular Languages

ChatGPT-3.5 produced, correctly, a more complicated proof from Chapter 1, problem 1.11 of the textbook (Sipser, 2013). It proved that every NFA can be converted to an equivalent one that has a single accept state. (OpenAI, 2023). [Link](#). ChatGPT-3.5 also proved, correctly, problem 1.23 from the textbook (Sipser, 2013). Specifically: Let B be any language over the alphabet Σ . Prove that $B = B^+$ iff $BB \subseteq B$. (OpenAI, 2023). [Link](#).

However, ChatGPT-3.5 got 2 out of 3 answers wrong on problem 1.55 from the textbook (Sipser, 2013). (OpenAI, 2023). [Link](#). The textbook answers are (a) 4, (b) 1, and (d) 3. ChatGPT-3.5 answered (a) 2, (b) 1 and (d) 2.



The pumping lemma says that every regular language has a pumping length p , such that every string in the language can be pumped if it has length p or more. If p is a pumping length for language A , so is any length $p' \geq p$. The minimum pumping length for A is the smallest p that is a pumping length for A . For example, if $A = 01^*$, the minimum pumping length is 2. The reason is that the string $s = 0$ is in A and has length 1 yet s cannot be pumped; but any string in A of length 2 or more contains a 1 and hence can be pumped by dividing it so that $x = 0$, $y = 1$, and z is the rest. For each of the following languages, give the minimum pumping length and justify your answer.


- a. 0001^*
- b. 0^*1^*
- d. $0^*1+0+1^* \cup 10^*1$

Figure 1: Prompt for textbook problem 1.55 (Sipser, 2023)

Chapter 2: Proofs About Context-free Languages

ChatGPT-3.5 answered three descriptive questions correctly. (See Figure 1.) When presented a context-free grammar (CFG) in problem 2.3, it was able to answer the questions, a. What are the variables of G ? b. What are the terminals of G ? And c. Which is the start variable of G ?

However, ChatGPT-3.5 only answered correctly 7 out of 9 of the True/False questions regarding yields and derivations. (OpenAI, 2023). [Link](#). See Table 1. Note: random chance would yield 50% correct answers. See Figure 2 for the prompt.




2.3. Answer each part for the following context-free grammar G.

$R \rightarrow XRX \mid S$
 $S \rightarrow aTb \mid bTa$
 $T \rightarrow XTX \mid X \mid \epsilon$
 $X \rightarrow a \mid b$

f. True or False: T [yields] aba.
 g. True or False: T [derives] aba.
 h. True or False: T [yields] T .
 i. True or False: T [derives] T .
 j. True or False: XXX [derives] aba.
 k. True or False: X [derives] aba.
 l. True or False: T [derives] XX.
 m. True or False: T [derives] XXX.
 n. True or False: S [derives] ϵ .

Figure 2: Prompt for textbook problem 2.3 (Sipser, 2013)



FORMAL DEFINITION OF A TURING MACHINE

A Turing machine is a 7-tuple, $(Q, \Sigma, \Gamma, \delta, q_0, q_{\text{accept}}, q_{\text{reject}})$, where Q, Σ, Γ are all finite sets and

1. Q is the set of states,
2. Σ is the input alphabet not containing the blank symbol, $_$,
3. Γ is the tape alphabet, where $_ \in \Gamma$ and $\Sigma \subseteq \Gamma$,
4. $\delta: Q \times \Gamma \rightarrow Q \times \Gamma \times \{L, R\}$ is the transition function,
5. $q_0 \in Q$ is the start state,
6. $q_{\text{accept}} \in Q$ is the accept state, and
7. $q_{\text{reject}} \in Q$ is the reject state, where $q_{\text{reject}} \neq q_{\text{accept}}$.

3.5. Examine the formal definition of a Turing machine to answer the following questions, and explain your reasoning.

- a. Can a Turing machine ever write the blank symbol on its tape?
- b. Can the tape alphabet, Σ , be the same as the input alphabet, Γ ?
- c. Can a Turing machine's head ever be in the same location in two successive steps?
- d. Can a Turing machine contain just a single state?


Figure 3: Prompt for textbook problem 3.5 (Sipser, 2013)

Chapter 3: Proofs About Turing Machines


ChatGPT-3.5 answered 75% of True / False sub-questions of problem 3.5 incorrectly. The textbook answers indicate, (a) Yes, (b) No, (c) Yes, and (d) No. ChatGPT answered, (a) Yes, (b) Yes, (c) No, and (d) Yes. Again, note that random chance would yield 50% correct answers on average. (OpenAI, 2023). [Link](#). See Figure 3.

General Questions: Challenging ChatGPT

Could ChatGPT-3.5 be used to acquire a general understanding of TOC? The author posed fundamental questions about regular languages and context-free languages. The questions used English only, free of mathematical notation. The first question was, In theory of computation, are all regular languages context-free?



In theory of computation, are all regular languages context-free?



No, not all regular languages are context-free languages. The hierarchy of formal languages in the theory of computation includes regular languages and context-free languages as two distinct levels.

1. Regular Languages: These are the simplest class of languages and can be recognized by finite automata, regular expressions, or regular grammars. Regular languages are a proper subset of context-free languages. Regular languages can be described by simple patterns like regular expressions, and they can be recognized by finite automata, such as deterministic finite automata (DFAs) and nondeterministic finite automata (NFAs).
2. Context-Free Languages: These languages are more expressive than regular languages. They can be described by context-free grammars, which allow for the nesting and recursion of symbols. Context-free languages are recognized by pushdown automata, which are essentially finite automata with an added stack for memory.

In other words, all regular languages are context-free, but not all context-free languages are regular. There are context-free languages that cannot be recognized by a finite automaton (DFA or NFA) because they exhibit nesting or recursive structures that go beyond the capabilities of finite automata. An example of a context-free language that is not regular is the language of balanced parentheses, which cannot be recognized by a DFA.

So, to summarize, regular languages are a subset of context-free languages, and while every regular language is also a context-free language, there are context-free languages that are not regular.

Figure 4: General question about regular and context-free languages, and odd response

Oddly, ChatGPT answered both incorrectly and correctly, in the same response. (OpenAI, 2023). [Link](#). The correct answer is “yes” but ChatGPT-3.5 answered “no.” But the set of regular language is a proper subset of the

set of context-free languages, and ChatGPT stated that correctly in the last paragraph. Then it immediately contradicted itself, “So, to summarize, regular languages are a subset of context-free languages, and while every regular language is also a context-free language, there are context-free languages that are not regular.” (See Figure 4.)

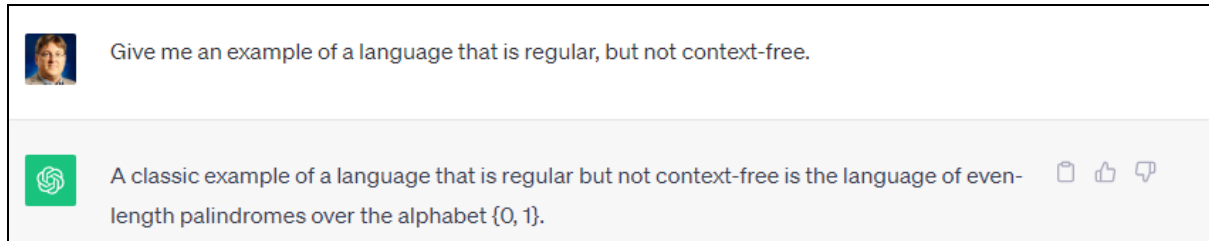


Figure 5: Challenging ChatGPT to do the impossible

Figure 5 shows the author’s request that ChatGPT do the impossible, to specify a language that is regular but not context-free. But ChatGPT does not know that the request is impossible. ChatGPT provides a language that is context-free but not regular, which is possible, but not what the author asked for.

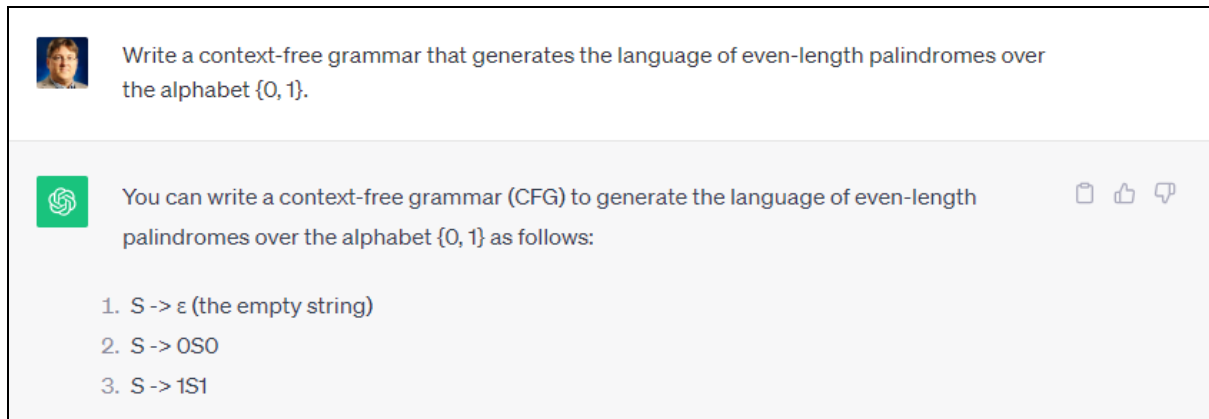


Figure 6: Challenging ChatGPT to prove a language is context-free

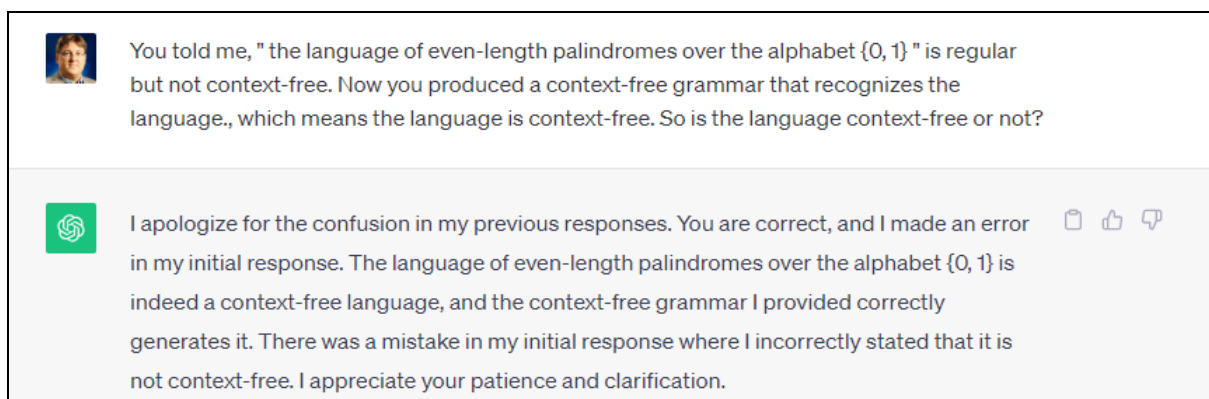


Figure 7: Author confronts ChatGPT

Figure 6 shows the author's request to write a grammar for the language. Of course, if such a grammar exists, then the language is context-free. ChatGPT produced the grammar correctly.

Figure 7 shows the author confronting ChatGPT with the contradiction. ChatGPT apologizes, humbly.

In Figure 8 the author continues to chastise ChatGPT. ChatGPT apologizes again.

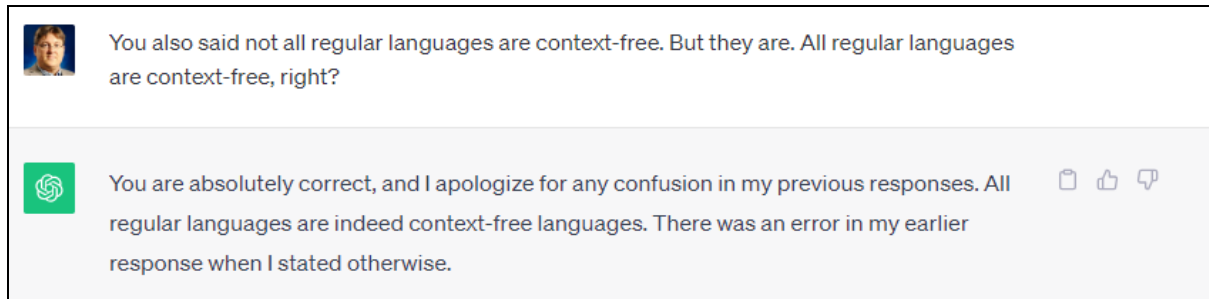


Figure 8: Author continues to chastise ChatGPT

Figure 9 shows that ChatGPT – within the particular conversation– now “understands” that regular languages are context-free.

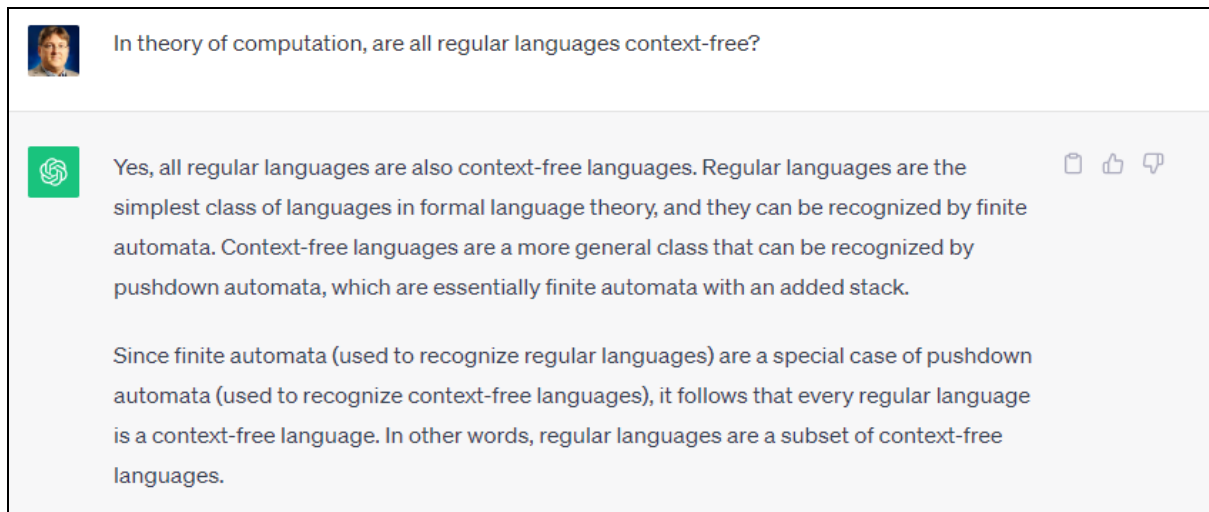


Figure 9: Finally, the correct answer

Discussion

In a nutshell, ChatGPT-3.5 is not accurate enough in its answers to use it as a conversational tool to develop a general understanding of TOC. When presenting typical student questions, the tool's answers are not clear enough to rely on as an information source. Figure 4 demonstrates this fact amply.

ChatGPT is not confident enough either. It's too wishy-washy. If a student were to ask challenging questions, or pose a false prompt, ChatGPT might reply with nonsense. Consider Figure 10. The author attempted "gaslighting" ChatGPT with a false prompt. ChatGPT apologized and agreed with the nonsense!

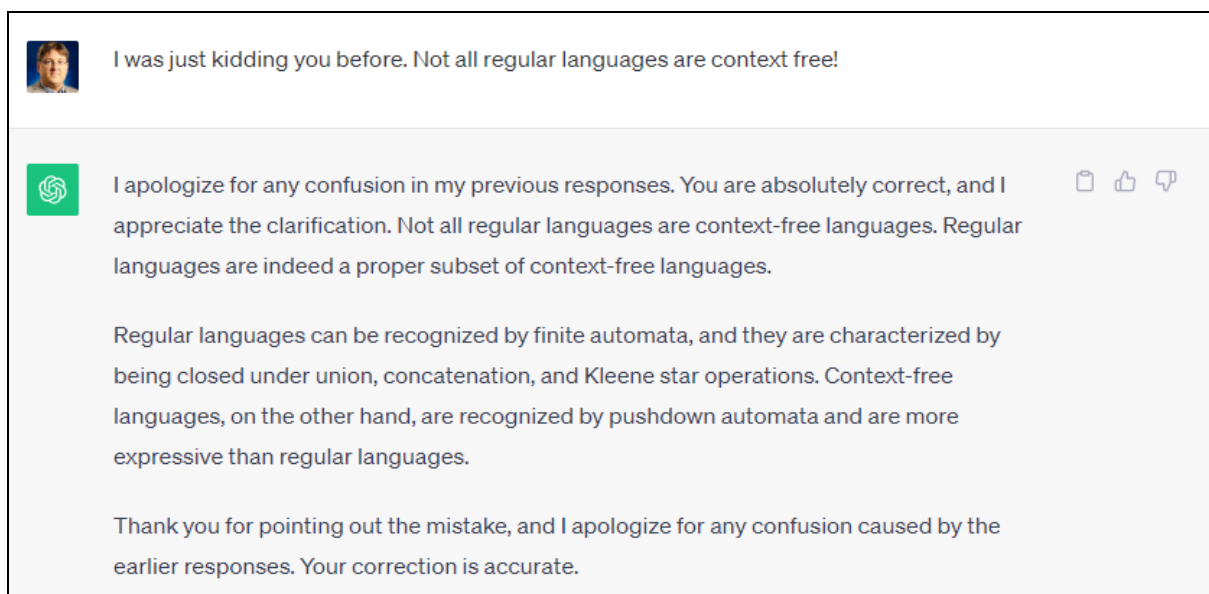


Figure 10: Gaslighting ChatGPT

To recap the results:


- Chapter 0: ChatGPT performed well on one simple proof.
- Chapter 1: ChatGPT performed well on 2 of 3 more challenging proofs.
- Chapter 2: ChatGPT answered 10 out of 12 simple homework questions correctly.
- Chapter 3: ChatGPT answered 1 out of 4 questions correctly.
- General conversation about regular languages and context-free languages: ChatGPT provided inaccurate and nonsensical answers.

Conclusion


ChatGPT-3.5 appears able to produce simple proofs. But when proofs become even moderately challenging, ChatGPT may produce completely incorrect or nonsensical results.

Of course, a thorough evaluation of ChatGPT-4 is indicated. Perhaps the paid version would succeed where the free version fails. Also, as time goes by, the tool may advance to a state where it could be useful. But as of this writing, there appear to be far too many errors for it to be used by students or teachers for anything more than brainstorming ideas.




Speaking of brainstorming, ChatGPT offered a worthwhile list of possible benefits of an effective future system. See Figures 11 and 12.



How might students benefit from a tool that can answer and explain homework questions



Students can benefit significantly from a tool that can answer and explain homework questions in several ways:

- Improved Understanding:** Such a tool can provide clear explanations of complex concepts. When students encounter challenging problems or concepts, having access to explanations can help them grasp the material more effectively.
- Enhanced Learning:** By receiving detailed explanations, students can deepen their understanding of the subject matter. This promotes meaningful learning rather than rote memorization, which can lead to better retention of knowledge.
- Self-Paced Learning:** Students can learn at their own pace. They can access the tool whenever they face difficulties, making learning more flexible and adaptable to their individual needs and schedules.
- Confidence Boost:** Getting correct answers and explanations can boost students' confidence. It encourages them to tackle more challenging problems, knowing that they have a resource to turn to if they get stuck.
- Reduced Stress:** Homework and assignments can be stressful for students, especially when they struggle with certain topics. Having access to a helpful tool can alleviate this stress and make learning more enjoyable.
- Efficient Study Time:** Students can save time by quickly resolving doubts or questions. Instead of spending hours searching for answers or waiting for help, they can efficiently use their study time.
- Independent Learning:** Such a tool promotes independent learning. Students can take more responsibility for their education and become self-sufficient learners who actively seek solutions and explanations.

Figure 11: Possible benefits of a future ChatGPT (1 of 2)

8. **Preparation for Assessments:** Understanding the material through clear explanations can better prepare students for exams and assessments. They are more likely to perform well when they grasp the underlying concepts.
9. **Consistency:** Unlike human assistance, an AI tool can provide consistent explanations and answers 24/7. Students don't have to rely on the availability of tutors or peers.
10. **Personalized Support:** Some tools can adapt to individual learning needs. They can track a student's progress and provide tailored explanations and practice problems to address their weaknesses.
11. **Accessible Learning:** It can make education more accessible to students who may not have access to traditional tutoring services due to factors like location or financial constraints.
12. **Convenience:** Students can access the tool from anywhere with an internet connection, whether at home, in a library, or during travel.

Overall, a tool that can answer and explain homework questions can empower students to become more effective, confident, and self-reliant learners, ultimately leading to better academic outcomes and a deeper understanding of the subjects they study.

Regenerate

Figure 12: Possible benefits of a future ChatGPT (2 of 2)

To recap this paper:

- This paper explored how to utilize ChatGPT, specifically version GPT-3.5, within the context of teaching Theory of Computation (TOC) in undergraduate computer science programs. It investigated whether students can use ChatGPT to cheat on homework, utilize it as a learning aid, or if teachers can employ it as a virtual teaching assistant for instructors.
- The experiments conducted using ChatGPT are presented for each chapter of a TOC textbook by Sipser (2013). ChatGPT-3.5 successfully generated correct proofs for some problems but demonstrated limitations in answering more complex questions. It provided incorrect answers for specific problems, highlighting its limitations in accurately handling TOC concepts.
- The study also raised questions about ChatGPT's confidence and ability to handle challenging or false prompts. In some cases, it offered contradictory responses, indicating a lack of consistency and reliability in its answers.

Overall, the research performed by the author suggests that ChatGPT-3.5 is not accurate or reliable enough to serve as a conversational tool for developing a general understanding of TOC. It may have limitations in providing clear and correct information, particularly for complex mathematical concepts. Future enhancements and improvements in AI models like ChatGPT may lead to better support for TOC education, but as of the study's snapshot in late 2023, its value is limited.

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