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Viewpoint

ChatGPT and Environmental Research

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CHATGPT: A CONVERSATIONAL AI THAT WILL FUNDAMENTALLY CHANGE THE WAY WE FIND INFORMATION

ChatGPT, the latest text-based artificial intelligence (AI) tool, has quickly gained popularity and is poised to revolutionize various aspects of our lives, including education and research. With its advanced natural language processing (NLP) capabilities, ChatGPT can understand and interpret human language like never before, allowing users to ask questions and receive answers in a conversational and intuitive manner. In this Viewpoint, we aim to draw from our NLP research background and share our experience and thoughts about ChatGPT by providing 10 real-world examples from different areas of environmental research. Our objective is to demonstrate how this emerging tool can be leveraged for research purposes while also highlighting potential pitfalls and challenges. By sharing these experiences, we hope to encourage the responsible and effective use of ChatGPT in research and beyond.

The generative pretrained transformer (GPT) is a cutting-edge natural language generation (NLG) model, and its latest iteration, GPT-3.5 (GPT-4[1] was released on March 14, 2023), was on a massive corpus of textual data, such as books, articles, and Web sites, with billions of model parameters (GPT-3 for the details).[2] ChatGPT is a fine-tuned application based on the GPT-3.5 engine at its initial release that uses supervised fine-tuning modeling (learning based on labeled prompt data), reward model construction (ranking the model responses), and proximal policy optimization (a class of reinforcement learning to optimize the reward policy). Two techniques used in ChatGPT are in-context learning and prompt engineering. In-context learning enables the agent to learn and adapt in real time, making it more versatile and capable of handling a wider range of situations. While ChatGPT can respond to a question with no additional hints (zero-shot prompts), its response quality improves by providing additional examples before asking questions (few-shot prompts). Prompt engineering involves designing model inputs, such as questions and statements, to obtain better outputs (i.e., responses).

The popularity of ChatGPT stems from its rapid, informative, and seemingly "intelligent" responses to any questions. However, it is important to question whether the model truly understands the content it produces, because mistakes and errors are also frequently obtained even for simple questions. As a result, it is essential to exercise caution and avoid over- and underestimating the potential and capability of the emerging tool (Figure 1).

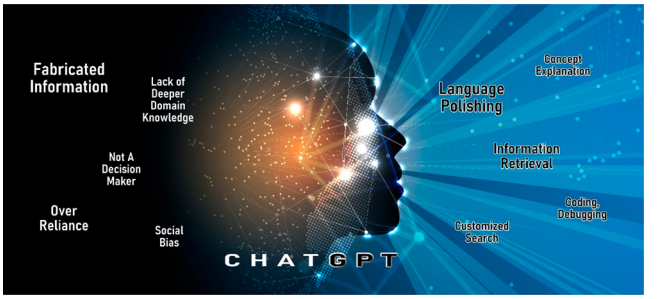

Figure 1. We should leverage the advantages (right side) that ChatGPT offers us while also exercising caution regarding potential hidden pitfalls (left side).

WHAT WE FOUND BENEFICIAL AND WHERE WE SEE POTENTIAL

Writing Improvement, Key Points, and Theme Identification. Writing is an essential part of research, and while ChatGPT should not be relied upon as the original content provider, it does provide great benefits in language polishing and identifying errors. This capability is particularly valuable for non-native speakers of the intended language. Moreover, ChatGPT can be used to translate text with more customized requests, and it can be utilized to summarize critical information from lengthy material. For example, by asking ChatGPT to identify key points, synopses, and main themes of a lengthy text, researchers can save time and gain a good understanding of all of the material to facilitate better comprehension (example S1). Alternatively, ChatGPT can

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generate suggestive titles from summaries or abstracts based on the main text, which may not meet specific needs but will certainly inspire new ideas. For example, we asked for different styles of titles based on the same abstract for tailored uses. The suggested review article titles proposed by ChatGPT were more formal, while the presentation titles were more vivid (example S2). Another valuable feature is that it can assist in adjusting and reducing writing content to meet word limitation requirements.

Sequential Information Retrieval. As a large language model (LLM), ChatGPT is good at basic information retrieval and concept explanation. When a concept is well-defined and appears in multiple sources during data collection, ChatGPT has a higher probability of explaining it correctly. This makes it particularly valuable for junior researchers who need help understanding complex concepts, such as terminologies, methods, and policies. It is also helpful for senior researchers who need to quickly familiarize themselves with new research areas from a large amount of information when tackling multidisciplinary problems. To test ChatGPT's abilities on more comprehensive information retrieval, we verified 10 trending-up environmental research topics, including PFAS, microplastics, life cycle assessment, and circular economy, which we previously identified.[3,4] ChatGPT successfully explained all concepts correctly on a general level (example S3). One great feature of LLMs (compared to Google or Baidu) is that they can "memorize" previous conversations ($\lesssim$3000 words for ChatGPT),[5] allowing for a series of customized questions to facilitate targeted information acquisition. For example, we tested sequential questions about direct lithium extraction, starting with a general explanation and progressing to specific materials used for selective lithium adsorption, and found the responses informative (example S4).

Coding, Debugging, and Syntax Explanation. As environmental research increasingly relies on data science, programming skills have become essential. Unfortunately, many environmental researchers lack the necessary training in programming. Fortunately, ChatGPT can assist by suggesting code snippets tailored to specific needs, identifying syntax errors and offering possible fixes, and explaining complicated or unfamiliar syntax to facilitate the learning process. For instance, if one looks to learn Python coding for predicting daily concentrations of organic carbon aerosols based on concentrations of other aerosol pollutants and meteorological conditions (example S5), ChatGPT can help with customized solutions such as data splitting, cross-validation, hyperparameter optimization, and more. Whenever you come across unfamiliar terms or syntax, ChatGPT makes it easy to obtain additional explanations.

WHAT WE FOUND PROBLEMATIC AND WHERE WE SHOULD BE CAUTIOUS

Fabricated Information and Lack of Updated, Domain Knowledge. The working mechanisms of a LLM determine that it could generate false or fabricated information. Perhaps one of the most significant concerns is that it provides made-up references or sources of specific text, such as fabricated DOI or URL links. Additionally, ChatGPT's training data extend to only 2021, and as it generates responses without access to the Internet, its limitations are magnified in areas where data are limited, such as the academic literature. As a result, ChatGPT often fails to provide state-of-the-art information in science and engineering.

We illustrated the aforementioned issues through an example in which we posed a series of questions about PFAS to ChatGPT. While ChatGPT was able to provide useful general information about PFAS, such as their physical and chemical properties (example S3), it incorrectly provided the chemical formula for PFOA when asked about the chemical structure of PFAS (example S6). Furthermore, when asked about whether a microbial electrochemical system (MES) was able to degrade PFAS, ChatGPT asserted that MES had been shown to do so (example S7). However, this information was not available to ChatGPT, as the first publication on MES degrading PFAS was released after ChatGPT's training data cutoff.[6] When asked to provide a source for this information, ChatGPT fabricated a seemingly credible literature reference and a made-up DOI that leads to an entirely unrelated article. The same pattern repeated across several devices and accounts, with ChatGPT providing different literature references, none of which were real. More examples demonstrating ChatGPT's lack of domain knowledge can be found in example S8. As a result, researchers are advised to exercise caution when relying on information from ChatGPT and to always fact-check responses.

Lack of Accountability in Decision Making. Environmental research involves a multitude of decision-making processes. Despite the constant updates and improvements made to ChatGPT, it is nearly impossible to completely eliminate false or fake information. Moreover, the decision-making process still heavily relies on human wisdom and judgment, and the involvement of AI remains controversial. In fact, researchers have discovered that ChatGPT generates responses with social bias,[7] raising doubts about relying on AI to solve environmental issues. As an added level of complexity, AI cannot be held accountable for their decisions, at least not yet. Therefore, caution must be exercised when inviting AI into decision-making processes, especially for environmental problems that are closely tied to public welfare.

Another area of concern in LLM pertains to the training materials used. Because a significant proportion of the corpus is derived from online platforms, there is a possibility that it could be deliberately manipulated to alter the behavior (e.g., poisoning attack[8]). Despite the filtering and weighting of the source dataset (e.g., the common crawl dataset in GPT-3[2]), as well as ChatGPT's preset rules to avoid responding to user-induced conspiracy theories, the extent to which it can filter out harmful information from the corpus employed for training remains unclear.

Opportunity Cost of Relying on ChatGPT. While ChatGPT brings much convenience and many benefits, the use of this tool may result in over-reliance, and its single output without diverse sources and opinions may hinder creative thinking. Traditional search engines offer a list of relevant information, while ChatGPT provides a single response that lacks diversity. Furthermore, depending too much on ChatGPT may impede one's learning curve for new knowledge. For example, if a trainee relies on the tool to generate programming code, the person may miss learning opportunities and failed to gain skills of their own. This issue is reflected in many schools' policies that ban or restrict the use of ChatGPT in learning settings.[9,10] To what extent ChatGPT should be involved in various tasks is at one's own discretion,

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Environ. Sci. Technol. 2023, 57, 17667−17670

but we recommend using it as an assistant rather than a substitute.

■ ADVANCED USES OF CHATGPT

Engineering Prompts to Obtain High-Quality Responses. We can and should improve the quality of responses from ChatGPT by using prompt engineering to design better questions. Typical guides include role-play, text format, style or tone, word limit, and other personalized requirements. In this example, we asked ChatGPT to explain "anaerobic digestion" with different engineered prompts (example S9). We asked ChatGPT to play different roles (e.g., presenter, family member, researcher, and professor) and offer different formats or styles of text (e.g., bullet points, short conversation, seminar speech, and reading material with mark-down style). By varying the prompts, we were able to obtain a range of responses that were tailored to different audiences and purposes. This approach enables the generation of high-quality responses that are both informative and engaging, making it a valuable tool for tasks such as content creation and knowledge sharing.

Few-Shot to Obtain a Fully Customized Response. It is possible to ask ChatGPT to understand self-contained rules for designing designated responses with required formats. For example, we employed ChatGPT and Midjourney (an AI drawing tool) to design and prepare the drawing shown in Figure S1. We first drafted a descriptive text that introduced the rules and formats used for AI drawing using Midjourney (example S10). We then asked ChatGPT to generate customized designing option suffixes for the AI drawing. The subsequent step involved requesting ChatGPT to produce drawing commands using the option suffixes. Finally, we applied the generated command in Midjourney to create and refine the drawing. The example demonstrates that we can utilize ChatGPT to perform more creative work beyond text and code with precise and actionable rules.

■ OUTLOOK

Disruptive technologies generate both opportunities and controversies. There is no doubt that ChatGPT will transform the world and make research and other work more automated or streamlined. We should embrace and take advantage of such changes to advance our missions, but we should also exercise caution to avoid pitfalls and recognize the limitations. It is worth noting that many publishers, including the American Chemical Society, have explicitly stated that AI tools like ChatGPT do not qualify for authorship. Any use of AI tools for text or image generation should be disclosed in the manuscript. As newer LLMs (like GPT-4) are introduced, they will become more reliable and capable of handling more complex tasks, which could alleviate some of the current issues. However, our approach to using ChatGPT and other AI tools should remain consistent. Humans are the primary content creators, and AI tools are our assistants, meant to improve the quality of our lives and the environment in which we live.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.3c01818.

Ten example interactions with ChatGPT covering different areas of environmental research (PDF)

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Notes

The authors declare no competing financial interest.

Biography

Zhiyong Jason Ren is a Professor in the Department of Civil and Environmental Engineering and the Andlinger Center for Energy and the Environment at Princeton University. His research focuses on the decarbonization and digitalization of the environmental and chemical sectors. His group uses electrochemistry, microbiology, and data science tools to understand the fundamental determining factors and develop models and technologies for resource recovery during environmental and chemical processes. Prof. Ren is an Associate Editor of *Environmental Science & Technology* and *Environmental Science & Technology Letters*.

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