



Discussion

Use of ChatGPT: What does it mean for biology and environmental science?

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HIGHLIGHTS

- We discuss what ChatGPT means for biology and environmental science.
- We examine its relevance to education, research, publishing, and science progress.
- We use it to generate 100 important questions for biology and environmental science.
- We highlight many benefits of its use but also draw attention to risks and potential harm.
- ChatGPT can revolutionize biology and environmental science but control measures are needed.

ARTICLE INFO

Editor: Elena Paoletti

Keywords:

Artificial intelligence

ChatGPT

Biology

Environmental science

Generative Pre-trained Transformer

Large language model

ABSTRACT

Artificial intelligence (AI) large language models (LLMs) have emerged as important technologies. Recently, ChatGPT (Generative Pre-trained Transformer) has been released and attracted massive interest from the public, owing to its unique capabilities to simplify many daily tasks of people from diverse backgrounds and social statuses. Here, we discuss how ChatGPT (and similar AI technologies) can impact biology and environmental science, providing examples obtained through interactive sessions with ChatGPT. The benefits that ChatGPT offers are ample and can impact many aspects of biology and environmental science, including education, research, scientific publishing, outreach, and societal translation. Among others, ChatGPT can simplify and expedite highly complex and challenging tasks. As an example to illustrate this, we provide 100 important questions for biology and 100 important questions for environmental science. Although ChatGPT offers a plethora of benefits, there are several risks and potential harms associated with its use, which we analyze herein. Awareness of risks and potential harms should be raised. However, understanding and overcoming the current limitations could lead these recent technological advances to push biology and environmental science to their limits.

1. Introduction

ChatGPT (Generative Pre-trained Transformer) is an artificial intelligence (AI) large language model (LLM) (<https://chat-gpt.org>), which is trained with reinforcement learning from human feedback (RLHF) and fine-tuned with proximal policy optimization (<https://openai.com/blog/chatgpt>). ChatGPT presents an advancement of previous LLMs and became freely available for research preview at the end of 2022 (OpenAI, San Francisco, USA), in order to receive user feedback and study its shortcomings and strengths (<https://openai.com/blog/chatgpt>). More recently,

a next-generation, multimodal (text and images) LLM, so called GPT-4, has been released, which outperforms ChatGPT in various aspects (<https://openai.com/product/gpt-4>). GPT-4 is more accurate, creative and collaborative, and capable of advanced reasoning (<https://openai.com/product/gpt-4>). In addition to process text as its predecessor, ChatGPT-4 can parse images and connect that information with a written question (i.e. multimodal). It scored higher than ChatGPT-3 in human tests, i.e. 90th and 99th percentile in Uniform Bar Examination (UBE) and Biology Olympiad, where ChatGPT was in the 10th and 31st percentile respectively (<https://openai.com/product/gpt-4>). UBE is a harmonized bar examination, developed by the Examination National Conference of Bar Examiners (NCBE) in the US, and consists of the Multistate Bar Examination (MBE), Multistate Essay Examination (MEE), and Multistate Performance Test (MPT) (<https://www.ncbex.org/exams/ube/>). Biology Olympiad is an exam of theoretical knowledge for high school biology students (<https://www.usabo-trc.org/>). As the Massachusetts Institute of

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Table 1

Examples of benefits that ChatGPT can offer to environmental science and ecology and means via which ChatGPT can provide the benefit. The table is created with outputs of ChatGPT (19 February 2023) that were obtained during different interactive sessions (Supplementary materials) and integrated. Note that what applies to ecology is applicable to biology overall.

Benefit	Means
Providing access to information	"ChatGPT has access to vast amounts of information on environmental science and ecology, including research papers, reports, and data sets. This information can be made accessible to individuals and organizations working in the field, helping them to stay up-to-date on the latest developments and make informed decisions."
Supporting research	"ChatGPT can be used to help researchers in environmental science and ecology analyze data, identify patterns, and generate new hypotheses. For example, it can be used to help identify relationships between different environmental variables, such as temperature and biodiversity, or to generate new ideas for conservation strategies." "Environmental science and ecology often involve analyzing large amounts of data. ChatGPT can help by assisting in data analysis and identifying patterns and trends that may be difficult for humans to recognize. This can save researchers a lot of time and help them to make more accurate and informed conclusions." (see also: Badini et al., 2023) "ChatGPT can help facilitate collaboration among researchers, policymakers, and stakeholders in the environmental health community. By providing a common platform for sharing information and ideas, ChatGPT can help advance the development of new solutions to environmental health challenges. For example, ChatGPT can help in bringing together experts in different fields to develop new strategies to mitigate the impact of climate change on public health."
Supporting risk assessment	"ChatGPT can help in assessing environmental risks to human health by analyzing large amounts of data on environmental factors such as pollution, climate change, or exposure to hazardous substances. ChatGPT can identify potential health risks and help develop strategies to reduce those risks."
Educating the public	"ChatGPT can be used to educate the general public on environmental science and ecology, helping to raise awareness about important issues such as climate change, habitat destruction, and biodiversity loss. It can be used to answer questions, provide explanations, and present information in a clear and accessible way. Overall, ChatGPT can be a valuable tool for anyone working in environmental science and ecology, providing access to information, supporting research, and educating the public." "ChatGPT can also help in educating the public on environmental health issues. By analyzing large amounts of scientific literature and synthesizing the key findings into more accessible formats, ChatGPT can help make complex environmental health concepts more understandable to the general public."
Providing insights and recommendations	"ChatGPT can analyze data and provide insights and recommendations based on that analysis. For example, it can suggest potential solutions to environmental problems, identify areas that require further research, and provide recommendations for policy changes."
Facilitating communication	"ChatGPT can be used to facilitate communication between researchers, students, and policymakers in environmental science and ecology. It can help to translate complex scientific concepts into language that is easier for non-experts to understand, and it can assist in cross-disciplinary communication between researchers in different field."
Improving efficiency	"ChatGPT can help to improve efficiency in environmental science and ecology by automating certain tasks, such as data analysis or literature review. This can free up time for researchers to focus on more complex and creative tasks."

Technology (MIT) Technology Review also explains, GPT-4 will be made available to those who sign up a waitlist and those who pay for ChatGPT Plus in a restricted, text-only mode (<https://www.technologyreview.com/2023/03/14/1069823/gpt-4-is-bigger-and-better-chatgpt-openai>). Although GPT-4 is still flawed (<https://www.nytimes.com/2023/03/14/technology/openai-new-gpt4.html>), the alignment of language models to

follow instructions is revolutionary, and these recent technological innovations came to stay for a long time ([Ali et al., 2023](#); [Badini et al., 2023](#); [Cahan and Treutlein, 2023](#); [Dwivedi et al., 2023](#); [Grünebaum et al., 2023](#); [Haleem et al., 2022](#); [Lecler et al., 2023](#); [Patel and Lam, 2023](#); [Stokel-Walker, 2023](#)). In this Discussion paper, authors aimed at illustrating what ChatGPT does mean for biology and environmental science. This exposition is assisted

Table 2

How can ChatGPT help to meet the United Nations (U.N.) Sustainable Development Goals (SDGs). Examples given by ChatGPT in interactive sections (Supplementary materials).

SDG	Means
SDG 3: Good Health and Well-being	"ChatGPT can help advance SDG 3 by analyzing vast amounts of health data, such as clinical data and medical literature, to identify patterns and relationships that can improve the diagnosis and treatment of diseases. ChatGPT can also help in developing predictive models to forecast disease outbreaks and develop strategies to prevent and control them." According to ChatGPT, it can analyze "a patient's medical history and current symptoms to provide tailored recommendations."
SDG 4: Quality Education	"ChatGPT can be used to improve educational outcomes by analyzing data on student performance and developing personalized learning approaches. ChatGPT can help educators to identify areas where students are struggling and provide targeted support. It can also help develop educational content and materials that are more accessible and inclusive for all learners, including those with disabilities or from disadvantaged backgrounds. Additionally, ChatGPT can assist in creating online platforms that can provide education to people in remote or underserved areas."
SDG 7: Affordable and Clean Energy	"ChatGPT can help with the development and implementation of sustainable energy solutions, such as solar and wind power, by analyzing data on energy consumption and production. It can also help to identify areas where energy efficiency can be improved, such as in buildings or transportation systems. ChatGPT can also be used to develop predictive models to forecast energy demand, which can help to optimize energy production and distribution."
SDG 11: Sustainable Cities and Communities	"ChatGPT can help in urban planning by analyzing data on traffic flow, energy use, and waste management. This can help to identify areas where improvements can be made, such as in the design of transportation systems or the construction of more energy-efficient buildings. ChatGPT can also be used to develop predictive models to forecast population growth and demand for resources, which can help to inform urban planning decisions."
SDG 13: Climate Action	"ChatGPT can be used to support climate change research by analyzing data on weather patterns, carbon emissions, and climate impacts. This can help to identify areas where mitigation and adaptation strategies are needed, and inform policy decisions. ChatGPT can also be used to support the development of renewable energy solutions, such as by analyzing data on wind and solar energy potential." "ChatGPT can help advance SDG 13 by analyzing climate data and developing predictive models to forecast the impact of climate change on various ecosystems and communities. ChatGPT can also help in developing strategies to reduce greenhouse gas emissions and mitigate the impact of climate change on vulnerable communities."
SDG 16: Peace, Justice, and Strong Institutions	"ChatGPT can be used to support the development of more effective and efficient justice systems by analyzing legal data and identifying areas where reforms are needed. It can also be used to monitor progress towards legal and governance-related goals, such as reducing corruption or increasing access to justice. Additionally, ChatGPT can be used to promote more inclusive decision-making processes, by engaging with stakeholders and ensuring that diverse perspectives are taken into account." "ChatGPT can also help in developing strategies to prevent and combat corruption and improve access to justice for marginalized communities."

by an interactive interaction with ChatGPT, which took place after the conceptualization and framework of this study were completed (and thus the research questions and steps were predefined) in order to avoid influence by reading outputs of ChatGPT. Text generated by ChatGPT is used in this paper to showcase some of its major capabilities, strengths and limitations, because this paper concerns ChatGPT itself, and recycling of ChatGPT-generated text should be avoided in research publications (see later sections). Here it should be noted that ChatGPT is an AI-LLM designed for language-processing tasks such as serving as search engine, answering questions, completing sentences, generating text, and soon widely available for editing and generating images. While ChatGPT is a significant technological advancement, it is not itself a scientific work. Therefore, this exposition does not imply that ChatGPT has a direct influence, but via its use.

2. What does ChatGPT mean for environmental science and biology?

When someone is under scrutiny, they deserve to be given the opportunity to explain themselves. Hence, in an interactive discussion with ChatGPT, we integrated different questions and answers and summarized positive contributions of ChatGPT to environmental science and ecology (and biology) (Table 1). The detailed answers of ChatGPT (Supplementary materials) illustrate that ChatGPT has its strengths but also its limitation. For example, it is true that it can contribute to the education of the public and raising awareness of important issues; however, by providing inaccurate information to non-experts can mislead the public. Then, ChatGPT can support research, but does not permit the upload of data to analyze statistically (at least not at this point of time), though it states it analyzes data (Discussion 6, Supplementary materials). This presents an example of inaccurate and incorrect information provided by ChatGPT. Moreover, ChatGPT suggests that it covers a large amount of information, including research papers, which can be made accessible to the user. However, ChatGPT fails to properly cite references it uses to generate output, and

neither does it make available files that can be downloaded (at least not at this point of time). Moreover, ChatGPT also provides fabricated references, and readers should be well aware of this and take the necessary precautions and measures (see analysis in Section 4). Despite these current limitations of ChatGPT, such LLMs are self-improving and new advances are emerging (Huang et al., 2022; Sun et al., 2022; Wang et al., 2022), which may result in overcoming many of the current limitations of ChatGPT. Its impact on education and scientific publishing are examined separately in more detail in next sections.

ChatGPT can help to meet the United Nations (U.N.) Sustainable Development Goals (SDGs). “Overall, ChatGPT’s ability to analyze vast amounts of data, develop predictive models, and generate new insights can help advance the SDGs by identifying areas where progress can be made and developing strategies to achieve these goals. ChatGPT’s ability to process and understand natural language also makes it an ideal tool for engaging with stakeholders and promoting more inclusive decision-making processes. By supporting more efficient, informed, and collaborative decision-making, ChatGPT can help accelerate progress towards the SDGs and create a more sustainable and equitable world” (ChatGPT, Supplementary materials). While these (Table 2) may seem questionable at its current stage, such LLMs are at their infancy and their revolutionary introduction may be succeeded by an unprecedented rapid development that will dynamically drive, shape, and potentially redirect the SDGs agendas. Even at the current level of technological advance, ChatGPT may provide important insights into SDGs.

Another advantage of ChatGPT is its ability to give answers to complex matters that a non-expert human would need a huge amount of time and energy to read various sources in order to be able to provide an answer. ChatGPT can provide such answers in seconds. As an illustrative example, ChatGPT shed light on how well humanity does in meeting the SDGs (Table 3). “Overall, the versatility and adaptability of ChatGPT makes it a valuable tool for promoting sustainable development and meeting the

Table 3
How well humanity does in meeting the Sustainable Development Goals (SDGs). Answers given by ChatGPT in interactive sections (Supplementary materials).

User input	ChatGPT output
Is humanity on good track in meeting the Sustainable Development Goals (SDGs)?	<p>“The progress towards meeting the Sustainable Development Goals (SDGs) is mixed. While there have been some successes, progress towards meeting some of the SDGs has been slow or stagnant in many regions, and some countries are actually regressing on certain indicators. According to the United Nations, progress towards meeting the SDGs has been uneven and has been further disrupted by the COVID-19 pandemic, which has exacerbated existing inequalities and created new challenges.</p> <p>As of 2021, progress has been made in areas such as reducing child mortality, improving access to education, and increasing access to electricity. However, significant challenges remain in areas such as ending poverty and hunger, ensuring access to clean water and sanitation, and achieving gender equality.</p> <p>Meeting the SDGs requires a sustained and coordinated effort by governments, businesses, civil society, and individuals, and progress will depend on factors such as political will, resource mobilization, and effective implementation strategies. Despite the challenges, there are also opportunities for progress, such as through new technologies, innovative financing mechanisms, and global partnerships.</p> <p>In summary, while progress towards meeting the SDGs is mixed, there is still an opportunity to achieve these goals if governments, businesses, and civil society continue to work together and prioritize sustainable development.”</p>
“Are you sure about your answer?”	<p>“As an AI language model, I try my best to provide accurate and reliable information based on my programming and available knowledge. However, the information I provide is always subject to limitations, such as the currency of my training data and any potential biases in the sources that were used to train me.</p> <p>Regarding the progress towards meeting the Sustainable Development Goals (SDGs), my answer reflects the general state of progress and challenges that have been reported by the United Nations and other reputable sources. However, progress towards meeting the SDGs is complex and multifaceted, and there may be varying perspectives and interpretations of the progress that has been made.</p> <p>If you have any specific concerns or questions about my answer, please feel free to let me know, and I will do my best to address them.”</p>
“Can you tell me more about it?”	<p>“Certainly. The United Nations regularly tracks progress towards meeting the Sustainable Development Goals (SDGs) through a series of indicators and reports. The most recent progress report, released in 2021, noted both successes and challenges in meeting the SDGs.</p> <p>For example, the report found that progress had been made in areas such as reducing child mortality, increasing access to education, and expanding access to electricity. However, progress has been slower in other areas, such as reducing poverty and hunger, ensuring access to clean water and sanitation, and achieving gender equality.</p> <p>Additionally, the COVID-19 pandemic has created new challenges and exacerbated existing inequalities, particularly in areas such as health, education, and income. According to the United Nations, progress towards the SDGs has been further disrupted by the pandemic, and many countries have regressed on certain indicators.</p> <p>Overall, the progress towards meeting the SDGs is complex and multifaceted, and it depends on a range of factors, such as political will, resource mobilization, and effective implementation strategies. While progress has been made in some areas, there is still a significant amount of work to be done to achieve the SDGs by the target year of 2030.”</p>

Table 4

One hundred important questions facing environmental science research. Answers were provided by ChatGPT (March 14 version, accessed 17 March 2023) in response to the question “Hello ChatGPT. Can you please give me 100 most important questions facing environmental science research?” (Discussion 8, Supplementary materials). Note that some questions overlap (e.g. questions 17, 31, 49 and 90 fully or partly overlap), which indicates that the list of 100 questions is sufficient to capture some of the most important questions. A cloud with the fifty most frequent words is presented in Fig. 1.

No.	Question
1	How can we reduce carbon emissions to mitigate climate change?
2	What is the impact of air pollution on human health?
3	What are the effects of ocean acidification on marine ecosystems?
4	How can we improve water quality in polluted rivers and lakes?
5	What is the impact of deforestation on biodiversity?
6	How can we develop sustainable agriculture practices?
7	What are the environmental impacts of plastic pollution?
8	How can we increase renewable energy production?
9	What are the effects of climate change on biodiversity?
10	How can we protect endangered species from extinction?
11	What are the environmental impacts of urbanization?
12	How can we reduce waste and increase recycling rates?
13	What is the impact of mercury pollution on ecosystems and human health?
14	How can we improve the sustainability of fisheries and aquaculture?
15	What are the effects of ocean warming on marine ecosystems?
16	How can we reduce the environmental impact of transportation?
17	What is the impact of noise pollution on wildlife?
18	How can we reduce the environmental impact of industrial activities?
19	What are the effects of defaunation on ecosystem functioning?
20	How can we promote sustainable tourism practices?
21	What is the impact of microplastic pollution on aquatic ecosystems and human health?
22	How can we improve the sustainability of mining and mineral extraction?
23	What are the effects of land-use change on ecosystem services?
24	How can we mitigate the impacts of natural disasters?
25	What is the impact of climate change on human health?
26	How can we improve the sustainability of the built environment?
27	What are the environmental impacts of oil and gas exploration and production?
28	How can we promote sustainable forest management?
29	What are the effects of invasive species on biodiversity and ecosystem functioning?
30	How can we reduce the environmental impact of food production and consumption?
31	What is the impact of noise pollution on human health?
32	How can we promote sustainable water use and management?
33	What are the environmental impacts of nuclear energy production?
34	How can we improve the sustainability of the textile industry?
35	What are the effects of climate change on agricultural productivity?
36	How can we reduce the environmental impact of the fashion industry?
37	What is the impact of light pollution on wildlife and human health?
38	How can we promote sustainable energy use in households and buildings?
39	What are the environmental impacts of hydraulic fracturing (fracking)?
40	How can we improve the sustainability of the electronics industry?
41	What are the effects of global warming on permafrost and polar ecosystems?
42	How can we reduce the environmental impact of the meat industry?
43	What is the impact of air pollution on crop yields?
44	How can we promote sustainable waste management practices in developing countries?
45	What are the environmental impacts of offshore wind energy production?
46	How can we improve the sustainability of the paper industry?
47	What are the effects of climate change on water resources and availability?
48	How can we reduce the environmental impact of the mining industry?
49	What is the impact of noise pollution on human well-being and quality of life?
50	How can we promote sustainable urban development and planning?
51	What are the environmental impacts of natural gas production and transportation?
52	How can we improve the sustainability of the plastic industry?
53	What are the effects of ocean deoxygenation on marine ecosystems?
54	How can we reduce the environmental impact of the fashion industry supply chain?
55	What is the impact of air pollution on wildlife?
56	How can we promote sustainable consumption and production patterns?
57	How can we improve the sustainability of the tourism industry?
58	What are the effects of climate change on coastal ecosystems and communities?
59	How can we reduce the environmental impact of the chemical industry?
60	What is the impact of pesticide use on pollinator populations?
61	How can we promote sustainable transportation systems?
62	What are the environmental impacts of conventional versus organic farming?
63	How can we improve the sustainability of the seafood industry?
64	What are the effects of climate change on human migration patterns?
65	How can we reduce the environmental impact of the pharmaceutical industry?
66	What is the impact of microplastic pollution on soil ecosystems?

Table 4 (continued)

No.	Question
67	How can we promote sustainable packaging practices?
68	What are the environmental impacts of bioplastics?
69	How can we improve the sustainability of the construction industry?
70	What are the effects of noise pollution on aquatic ecosystems?
71	How can we reduce the environmental impact of the mining industry on indigenous communities?
72	What is the impact of light pollution on human health and well-being?
73	How can we promote sustainable business practices?
74	What are the environmental impacts of renewable energy production?
75	How can we improve the sustainability of the automotive industry?
76	What are the effects of climate change on cultural heritage sites?
77	How can we reduce the environmental impact of the aviation industry?
78	What is the impact of plastic pollution on soil ecosystems?
79	How can we promote sustainable fishing practices?
80	What are the environmental impacts of genetically modified crops?
81	How can we improve the sustainability of the wine industry?
82	What are the effects of climate change on forest fires?
83	How can we reduce the environmental impact of the shipping industry?
84	What is the impact of air pollution on soil health and productivity?
85	How can we promote sustainable land use and management practices?
86	What are the environmental impacts of meat alternatives?
87	How can we improve the sustainability of the chocolate industry?
88	What are the effects of climate change on infectious diseases?
89	How can we reduce the environmental impact of the textile industry supply chain?
90	What is the impact of plastic pollution on freshwater ecosystems?
91	How can we promote sustainable energy use in developing countries?
92	What are the environmental impacts of hydroelectric power production?
93	How can we improve the sustainability of the cosmetics industry?
94	What are the effects of climate change on soil health and productivity?
95	How can we reduce the environmental impact of the mining industry on water resources?
96	What is the impact of air pollution on marine ecosystems?
97	How can we promote sustainable food systems?
98	What are the environmental impacts of the fashion industry on human rights?
99	How can we improve the sustainability of the fashion industry supply chain?
100	What are the environmental impacts of ocean acidification on marine ecosystems?

SDGs. By leveraging the power of artificial intelligence and machine learning, ChatGPT can support evidence-based decision-making, data analysis, and collaboration, all of which are critical for achieving the SDGs” (ChatGPT, Supplementary materials).

Last but not least, “ChatGPT’s advanced capabilities in data analysis, risk assessment, predictive modeling, public education, and policy development can all contribute to the advancement of environmental health agendas. By enabling researchers and policy-makers to work more efficiently and effectively, ChatGPT has the potential to help identify and address environmental health issues more quickly and accurately, and to develop policies and interventions that better protect public health ... By helping researchers and policy-makers to make more informed decisions, ChatGPT has the potential to accelerate progress towards a healthier, more sustainable future” (ChatGPT, Supplementary materials).

As an example of how ChatGPT can be used to expedite scientific process, we sought to generate 100 questions important for environmental science research and biology research (Tables 4–5). Without AI and AI-assisted tools in scientific discourse reaching this outcome would require collection of viewpoints from hundreds of people worldwide and months of work to reach the desired outcome (Armstrong et al., 2023). Besides, the views of individual researchers are subjective, whereas AI-generated views (questions) are not driven by human feelings and personal philosophies and thus are free from individualized subjectivity. Instead, they are generated using vast information at a global scale. These questions can provide an important basis for future directions, new insights, and further developments (note: the question lists are indicative and only an example of how ChatGPT and similar technologies can help by providing a basis upon which to build). For instance, the questions facing environmental science research largely concern sustainability, and 30, 16, 11, 10, 9, 7, 5, and 4 % of the questions cite ‘sustaina’, ‘ecosystem’, ‘climate change’, ‘human’, ‘health’, ‘plastic’, ‘air pollution’ and ‘noise’, respectively (Table 4). The five most cited words are ‘impact’ (48), ‘sustainability’ (30), ‘environment’

Table 5

One hundred important questions facing biological research. Answers were provided by ChatGPT (March 14 version, accessed 17 March 2023) in response to the question “Hello ChatGPT. Can you please give me 100 most important questions facing biological research?” (Discussion 8, Supplementary materials). DNA: Deoxyribonucleic acid; RNA: Ribonucleic acid. A cloud with the fifty most frequent words is presented in Fig. 2.

No.	Question
1	How does the immune system recognize and respond to pathogens?
2	What are the molecular mechanisms of gene expression and regulation?
3	How do cells differentiate and specialize during development?
4	What are the genetic and environmental factors that contribute to the development of complex diseases?
5	How do organisms adapt and evolve in response to changing environments?
6	What are the underlying mechanisms of aging and age-related diseases?
7	What are the molecular and cellular mechanisms of learning and memory?
8	How do proteins fold and interact with each other?
9	What are the genetic and environmental factors that contribute to behavior and personality?
10	How do neurons communicate and process information in the brain?
11	What are the molecular mechanisms of drug addiction and tolerance?
12	What are the genetic and environmental factors that contribute to obesity and metabolic disorders?
13	How do viruses infect and replicate within host cells?
14	What are the molecular and cellular mechanisms of cancer development and progression?
15	How do proteins and nucleic acids interact to control gene expression?
16	What are the genetic and environmental factors that contribute to neurological disorders?
17	How do organisms respond to environmental stressors and toxins?
18	What are the molecular mechanisms of circadian rhythms and sleep?
19	How do immune cells differentiate and interact to mount an immune response?
20	What are the genetic and environmental factors that contribute to psychiatric disorders?
21	How do cells repair DNA damage and maintain genomic stability?
22	What are the molecular mechanisms of neurotransmitter release and uptake?
23	What are the genetic and environmental factors that contribute to drug metabolism and toxicity?
24	How do cells and organisms maintain homeostasis?
25	What are the molecular mechanisms of gene editing and genetic engineering?
26	How do cells and tissues regenerate and repair after injury?
27	What are the genetic and environmental factors that contribute to aging-related cognitive decline?
28	How do bacterial and fungal pathogens interact with host cells and tissues?
29	What are the molecular mechanisms of DNA replication and cell division?
30	What are the genetic and environmental factors that contribute to cardiovascular disease?
31	How do plants and microbes interact and influence ecosystem dynamics?
32	What are the molecular and cellular mechanisms of neurodegenerative diseases?
33	How do hormones and signaling molecules control cellular responses and behaviors?
34	What are the genetic and environmental factors that contribute to autoimmune diseases?
35	How do organisms respond to changes in light and temperature?
36	What are the molecular mechanisms of muscle contraction and movement?
37	What are the genetic and environmental factors that contribute to respiratory disease?
38	How do cells and tissues respond to mechanical forces and stresses?
39	What are the molecular mechanisms of membrane transport and signaling?
40	What are the genetic and environmental factors that contribute to developmental disorders?
41	How do bacteria and archaea adapt and evolve in response to antibiotics?
42	What are the molecular mechanisms of cell death and apoptosis?
43	What are the genetic and environmental factors that contribute to chronic pain?
44	How do cells and tissues interact and communicate during embryonic development?
45	What are the molecular mechanisms of ion channel function and regulation?
46	What are the genetic and environmental factors that contribute to gastrointestinal disease?
47	How do organisms respond to changes in atmospheric composition and climate?
48	What are the molecular mechanisms of synaptic plasticity and learning?
49	What are the genetic and environmental factors that contribute to metabolic syndrome?
50	How do cells and tissues respond to oxidative stress and damage?
51	What are the molecular mechanisms of protein trafficking and secretion?
52	What are the genetic and environmental factors that contribute to kidney disease?
53	How do organisms sense and respond to changes in pH and osmolarity?
54	What are the molecular mechanisms of protein degradation and turnover?
55	What are the genetic and environmental factors that contribute to hearing loss?

Table 5 (continued)

No.	Question
56	How do bacteria and viruses evolve resistance to antibiotics and antivirals?
57	What are the molecular mechanisms of RNA processing and regulation?
58	What are the genetic and environmental factors that contribute to rare diseases?
59	How do cells and tissues respond to changes in oxygen availability and hypoxia?
60	What are the molecular mechanisms of epigenetic regulation and inheritance?
61	What are the genetic and environmental factors that contribute to neurodevelopmental disorders?
62	How do organisms sense and respond to changes in nutrient availability?
63	What are the molecular mechanisms of protein-protein interactions and complexes?
64	What are the genetic and environmental factors that contribute to immune system disorders?
65	How do cells and tissues respond to changes in extracellular matrix and adhesion?
66	What are the molecular mechanisms of membrane fusion and exocytosis?
67	What are the genetic and environmental factors that contribute to reproductive disorders?
68	How do organisms sense and respond to changes in gravity and mechanical stress?
69	What are the molecular mechanisms of protein misfolding and aggregation?
70	What are the genetic and environmental factors that contribute to metabolic disorders in pregnancy?
71	How do cells and tissues respond to changes in pH and ionic strength?
72	What are the molecular mechanisms of lipid metabolism and transport?
73	What are the genetic and environmental factors that contribute to skin and hair disorders?
74	How do organisms sense and respond to changes in light quality and intensity?
75	What are the molecular mechanisms of protein localization and targeting?
76	What are the genetic and environmental factors that contribute to rare genetic disorders?
77	How do cells and tissues respond to changes in mechanical tension and stretching?
78	What are the molecular mechanisms of membrane structure and dynamics?
79	What are the genetic and environmental factors that contribute to blood disorders?
80	How do organisms sense and respond to changes in temperature and thermal stress?
81	What are the molecular mechanisms of protein quality control and chaperone function?
82	What are the genetic and environmental factors that contribute to bone and joint disorders?
83	How do cells and tissues respond to changes in intracellular signaling and second messengers?
84	What are the molecular mechanisms of ion channel gating and modulation?
85	What are the genetic and environmental factors that contribute to endocrine disorders?
86	How do organisms sense and respond to changes in atmospheric gases and pollutants?
87	What are the molecular mechanisms of cellular respiration and energy production?
88	What are the genetic and environmental factors that contribute to liver disease?
89	How do cells and tissues respond to changes in electrical fields and currents?
90	What are the molecular mechanisms of cytoskeleton structure and dynamics?
91	What are the genetic and environmental factors that contribute to eye disorders?
92	How do organisms sense and respond to changes in magnetic fields and electromagnetic radiation?
93	What are the molecular mechanisms of DNA repair and recombination?
94	What are the genetic and environmental factors that contribute to dental and oral disorders?
95	How do cells and tissues respond to changes in calcium signaling and homeostasis?
96	What are the molecular mechanisms of cellular trafficking and secretion?
97	What are the genetic and environmental factors that contribute to immune system aging?
98	How do organisms sense and respond to changes in water availability and drought?
99	What are the molecular mechanisms of protein degradation by the ubiquitin-proteasome system?
100	What are the genetic and environmental factors that contribute to connective tissue disorders, such as Ehlers-Danlos syndrome and Marfan syndrome, and how can they be diagnosed and treated?

(30), ‘industry’ (25), and ‘pollution’ (18), suggesting the broader relevance of these topics (Fig. 1). Moreover, many of the questions facing biological research concern biological responses to environmental changes, which further indicates how largely biology is centered on the environment nowadays. Specifically, the words ‘genetic’ (37), ‘environment’ (33), ‘mechanisms’ (32) and ‘molecular’ (32), cells (25) and response (25), and changes (18) rank top five. Hence, by studying such questions one may identify important aspects facing research (and other sectors). Furthermore, it can help



Fig. 1. Cloud with the fifty most frequent words appearing in ChatGPT-generated 100 important questions facing environmental science research (see Table 4). Common words were excluded (and, are, can, how, in, is, of, on, the, to, versus, we, what). Words with variation in their form were merged ('ecosystem' with 'ecosystems', 'agriculture' with 'agricultural', 'develop' with 'development' and 'developing', 'impact' with 'impacts', 'environment' with 'environmental', 'fishing' with 'fisheries', and 'pollution' with 'polluted'). Note: the most-frequently-appearing non-common word ('impact') appeared 48 times.

users to understand where some areas of research may require further attention or where they are headed. For instance, ChatGPT indicated the question of "what is the impact of air pollution on wildlife", and this a largely unknown area. For example, it has recently emerged that air pollution is associated with bird mortalities, and this requires further research

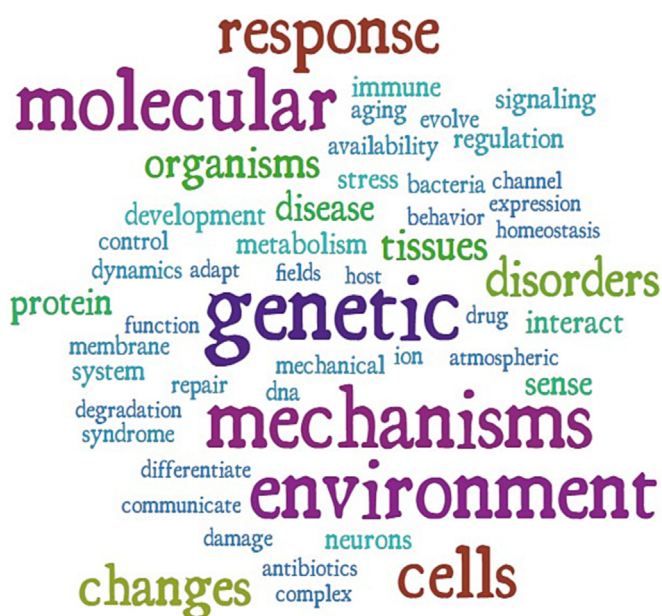


Fig. 2. Cloud with the fifty most frequent words appearing in ChatGPT-generated 100 important questions facing biological research (see Table 5). Common words were excluded (e.g. and, are, contribute, do, during, factors, how, in, of, that, the, to, what, with). Words with variation in their form were merged (e.g. 'bacteria' with 'bacterial', 'cells' with 'cell' and 'cellular', 'replicate' with 'replication', 'respond' with 'response' and 'responses', etc.). Moreover, a set of words related to neurons were merged ('neurogenerative', 'neurodevelopmental', 'neurological', 'neurons', and 'neurotransmitter'). Notes: The color and size of the words vary with frequency. The words 'contribute' and 'factors' appeared 31 times each. As a reference, the most-frequently-appearing non-common word ('genetic') appeared 37 times.

(Liang et al., 2020; Reif et al., 2023). Similarly, "the impact of air pollution on marine ecosystems" requires considerable research to understand. For example, it is unknown how ozone –the predominant air pollutant for vegetation- can impact marine ecosystems, though it has the potential, such as by affecting macrophytes (Feder and Sullivan, 1969) and potentially altering trophic interactions. Likewise, the impact of noise pollution on aquatic ecosystems is poorly understood, yet in many places of the world night bars with strong lights and noise operate alongside the seashore.

ChatGPT can be used to further narrow down a list, a task that could be highly challenging for a researcher. As an example ChatGPT generated ten important questions for each science (Tables 6–7). Nevertheless, it acknowledges that the questions are illustrative and not definite or exhaustive: "As an AI language model, I do not have a personal opinion or belief system. The questions I provided are based on current scientific research and discussions in the fields of biology and environmental science. However, there may be other important questions that are equally or more significant depending on different perspectives, research areas, and social, economic, and political contexts. The importance of a question can also vary over time as new discoveries, challenges, and opportunities arise. Therefore, the list I provided is not definitive or exhaustive but aims to illustrate some of the current issues and challenges facing these scientific fields" (ChatGPT, Supplementary materials).

Another strength of ChatGPT is its ability in coding. It can help the modeling community to develop and improve models. This is especially important for environmental researchers, who are excelled in science but are not professional in model developing. A lot of time can be spent to revise model and/or add new modules (coding), which usually also increases the computation load and reduces the efficiency in models. This feature of ChatGPT can save considerable time, allow researchers to focus on more important and creative tasks, and expedite scientific progress. However, the outputs of the ChatGPT should be supervised by experienced professionals, at least until ChatGPT reaches such a level that can perfectly execute such applications and debug problematic coding. Along a similar line, the non-publicly available successor of ChatGPT, GPT-4, appears to be able to create digital games in minutes (<https://www.independent.co.uk/tech/chatgpt-gpt-4-ai-video-games-b2301358.html>) [see also <https://www.sitepoint.com/utilizing-gpt-4-for-game-development/> and <https://www.technologyreview.com/2023/03/21/1070102/how-ai-experts-are-using-gpt-4/>]. However, the AI system will not always write the code in full and/or the developer has to follow up with additional queries to the AI in a dialectic back and forth to get it to create the code in full (as shown also in other sections of this paper, at times it will even acknowledge its mistakes or incomplete information and provide further information/code). These features highlight the potential of GPTs to transform many aspects of research and applications, and we may soon find ourselves working in entirely new ways that we did not foresee –at least not this soon. However, the users still need to know what they are doing, what is needed and/or missing, and the general design process. The labor of creating the code itself can be done by the AI, and the GPTs will be more useful as an AI assistant rather than doing all the intellectual or research work (at least based on how we know GPTs and other LLMs today).

AI is evolving rapidly in the healthcare system too, and is expected to transform the sector of health and medicine (Chen and Decary, 2020; Rajpurkar et al., 2022). Recognizing the potential of AI to reshape health sector, the World Health Organization (WHO) also issued the first report on AI health in mid. 2021, which also included six principles for guiding its design and use to minimize the risks and maximize the benefits of AI use (WHO, 2021). These principles included (i) protection of human autonomy, (ii) promotion of the well-being of humans, safety, and public interest, and (iii) assurance of explainability, transparency, and intelligibility (WHO, 2021). The remaining principles were (iv) fostering accountability and responsibility, (v) ensuring equity and inclusiveness, and (vi) promoting responsive and sustainable AI (WHO, 2021). Higher cognitive thinking represents the capacity of an AI tool to perform sophisticated cognitive processes, including

Table 6

Ten important questions facing environmental science research. Answers were provided by ChatGPT (March 14 version, accessed 18 March 2023) in response to the question “Hello ChatGPT. Can you please give me 10 most important questions facing environmental science research?” (Discussion 8, Supplementary materials).

No.	Question
1	“How can we mitigate and adapt to the impacts of climate change, such as rising sea levels, more frequent extreme weather events, and shifts in ecosystems?”
2	“How can we ensure sustainable and equitable use of natural resources, such as water, forests, and minerals, in a way that balances economic development with environmental protection?”
3	“How do pollutants, such as plastics, chemicals, and heavy metals, affect human and ecosystem health, and what can we do to reduce their impact?”
4	“How can we protect and restore biodiversity and ecosystem services, such as carbon sequestration, pollination, and soil fertility, in the face of habitat loss, invasive species, and climate change?”
5	“How can we improve waste management practices, including recycling, composting, and waste reduction, to reduce the amount of waste that ends up in landfills or the environment?”
6	“How can we promote sustainable transportation systems, including public transit, biking, and walking, to reduce greenhouse gas emissions and improve air quality?”
7	“How can we integrate traditional ecological knowledge and local communities into environmental management and decision-making processes?”
8	“How can we develop and implement effective policies and regulations to promote environmental sustainability at the local, national, and global levels?”
9	“How can we better understand and model the complex interactions between humans and the environment, including social, economic, and political factors that influence environmental outcomes?”
10	“How can we develop and scale up clean energy technologies, such as solar, wind, and geothermal power, to reduce greenhouse gas emissions and promote energy security?”

reasoning, decision-making, perceiving, and problem-solving, and entails critical understanding and processing of abstract ideas, assessment and application of context-specific data, and generation of insights by utilizing pre-existing learned information and attained experience (Ghosh and Bir, 2023). Nevertheless, recent studies indicate the potential of ChatGPT to successfully address higher-order thinking in medical healthcare. For instance, an analysis of 585 evaluations revealed that ChatGPT responses received even higher scores, compared to physician responses, and the responses were characterized by quality and empathy (Ayers et al., 2023). Another study examined the capacity of ChatGPT to solve higher-order reasoning in pathology by assessing responses to 100 higher-order reasoning queries based on scoring (0 to 5 scale) by three expert pathologists (Sinha et al., 2023). The average response time to each question was 45.3 ± 7.1 s, and the median score reached 4.08 (Q1–Q3: 4–4.3), indicating that an approximate score of 80 % can be achieved (Sinha et al., 2023). The accuracy of the responses was characterized by a ‘relational’ level according to the structure of the observed learning outcome (SOLO) taxonomy (Sinha et al., 2023). In a different study, 200 questions of medical biochemistry reasoning, which require higher-order thinking, were administered to ChatGPT (Ghosh and Bir, 2023). The answers were evaluated by expert biochemistry academicians using a scale from 0 to 5, and the median score of the ChatGPT-generated answers was 4 (Q1 = 3.5, Q3 = 4.5) (Ghosh and Bir, 2023). These recent advances illustrate the potential successful use of ChatGPT in medical healthcare applications requiring higher-order thinking; however, continuous training, developments, and improvements are essential to maximize the performance and outcomes (Ghosh and Bir, 2023).

3. Impact of ChatGPT on environmental science and biology education

ChatGPT can assist pedagogical activities in the fields of environmental science and biology in diverse ways, such as by providing millions of students worldwide an opportunity to **improve their writing** (see footnote 3 too). As an example, we asked ChatGPT to help improve a text with grammatical and other language errors, which it did (Table 8). While it is known that ChatGPT is currently unnecessarily wordy, which is an issue in scientific writing, the users can interact with ChatGPT in an engaging way until they receive a satisfying outcome (Table 8). Moreover, in a series of conversations we had with ChatGPT, we examined answers to same questions that were asked at different times. We noticed that the answers of ChatGPT can vary, (e.g. Discussion 2 versus Discussion 3 and Discussion 4 versus Discussion 5 in Supplementary materials). This would be expected as LLMs evolve with the increase of input information and self-improve (Huang et al., 2022), but users should consider this point.

ChatGPT can further improve academic activities by different means. For example, it can **support personalized learning experiences**, such as

recommending further opticoacoustic material for study or generating quiz questions based on the area of interest and needs of the user, whether teacher or student (ChatGPT; Supplementary materials). This can **improve teaching and learning efficiency**, and ChatGPT can be used to automate various tasks that would save time to be allocated to more creative and complex tasks (ChatGPT; Supplementary materials). For example, it can be used by educators to assist in the preparation of examinations to save considerable time; however, users should use the outputs with caution and as a preliminary template to be subjected to careful evaluation and improvement as needed (Discussion 9, Supplementary materials). ChatGPT can also **facilitate remote learning** when not in classroom, which is particularly important for those who cannot be physically present in class because they live in remote areas or for other reasons. These can further **increase student engagement**. Moreover, by **translating from one language to another**, ChatGPT can provide excellent support to students who's English is not their primary language and may face difficulties in understanding scientific concepts. ChatGPT appears to perform well with translation, although its function may be limited with large texts (Table 9). While its translation includes errors that are obvious even to a careless reader, it is overall of sufficient quality to both comprehend the story and improve with minor edits if needed. Furthermore, ChatGPT can help students **to learn and improve foreign languages** through simulations of real-life dialogues with native speakers, as well as **to research**, such as by suggesting important literature, keywords for database searching, and summary generation (ChatGPT; Supplementary materials).

Despite the benefits ChatGPT can offer to academic activities, there are potential risks and harms that should be acknowledged (Choi et al., 2023). These include (i) “**over-reliance** on ChatGPT, which could lead to a reduction in critical thinking and independent research skills” and, “if teachers become too reliant on ChatGPT for support and feedback, they may not develop the necessary skills to engage with students in creative and interactive ways”; (ii) “**perpetuate biases** in academic research and teaching if the training data used to develop the model is biased”; (iii) “contribute to a **reduction in human interaction** in academic settings, which could have negative impacts on student motivation, mental health, and social skills”; (iv) facilitate “**cheating or plagiarizing** academic work, which could harm the integrity of academic activities”; and (v) “a potential for **misuse or hacking** of ChatGPT, which could lead to the spread of misinformation or manipulation of academic activities” (ChatGPT; Supplementary materials). Moreover, (vi) “ChatGPT could be used to **automate tasks that require human input**, such as grading or providing feedback on assignments. While this may save time, it could also lead to a reduction in the quality of feedback and teaching that students receive.” These could further result in **less diverse perspectives and approaches in academic activities**. At least initially, incorporation of ChatGPT in teaching activities could introduce a heavily **increased workload for educators** to train and integrate it into their teaching activities (ChatGPT, Supplementary materials). The over-reliance on ChatGPT could also “lead to a

Table 7

Ten important questions facing biological research. Answers were provided by ChatGPT (March 14 version, accessed 18 March 2023) in response to the question “Hello ChatGPT. Can you please give me 10 most important questions facing biological research?” (Discussion 8, Supplementary materials). COVID-19: Coronavirus disease 2019 caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

No.	Question
1	“What is the origin of life? How did the first living organisms arise from non-living matter?”
2	“How does the human brain work, and what can we do to treat or prevent neurodegenerative diseases such as Alzheimer’s or Parkinson’s?”
3	“How can we better understand and combat diseases caused by viruses such as COVID-19, Ebola, or Zika?”
4	“What are the underlying genetic and environmental factors that contribute to the development of cancer, and how can we improve cancer prevention, diagnosis, and treatment?”
5	“How can we develop sustainable agriculture practices that maximize crop yields while minimizing negative impacts on the environment?”
6	“How do different species evolve, and what are the mechanisms behind genetic variation and adaptation?”
7	“How can we harness the potential of stem cells for tissue regeneration and disease treatment?”
8	“How can we better understand and conserve biodiversity, particularly in the face of climate change and habitat destruction?”
9	“How do microbes and other microorganisms interact with their environment, and what implications do these interactions have for human health and environmental sustainability?”
10	“How can we develop new therapies and treatments for genetic disorders, such as cystic fibrosis, sickle cell anemia, or Huntington’s disease?”

reduction in critical thinking and independent research skills. If students or researchers rely too heavily on the model to provide answers or insights, they may miss opportunities to develop these important skills” (ChatGPT; Supplementary materials). Besides, over-reliance may “also negatively **impact teacher-student relationships**. If educators use ChatGPT to provide feedback to students rather than engaging with them directly, this could lead to a breakdown in the teacher-student relationship” (ChatGPT; Supplementary materials). Further, “ChatGPT may require access to large amounts of data in order to be effective, which could raise **concerns about privacy and security**. If the data used to train the model is not properly secured, this could lead to breaches and the exposure of sensitive information” (ChatGPT; Supplementary materials). Here, it is important to highlight that currently ChatGPT provides wrong answers and often insists to them, which may be hard to be identified unless by a professional (see Supplementary materials and succeeding sections; see also <https://www.cnbc.com/2023/03/16/microsoft-justifies-ais-usefully-wrong-answers.html>), and this contributes to perpetuate biases. Nevertheless, one may expect that these limitations will overcome at some point, considering also the self-improving ability and continuous evolution of such AI technologies. Moreover, ChatGPT may self-correct some of its biases if instructed to do so. Thus an nth-layer of confirmation prompting can reduce the uncertainty in ChatGPT outputs, but accurate questioning is also critical for achieving effective response from ChatGPT.

As mentioned, ChatGPT and other AI technologies of this kind can be used to generate essays. As an illustrative example, after finalizing the Introduction of this paper, we asked ChatGPT “Well, I decided to write a scientific paper about you, in particular the role you can play in environmental and biological sciences. Could you please synthesize an Introduction for me?” We received the following response “Sure, I can help you with that. Here’s a possible

introduction for a scientific paper exploring the potential role of AI language models such as myself in the fields of environmental and biological sciences: Introduction: Artificial intelligence (AI) has been rapidly advancing over the past decade, providing new opportunities for scientific research and discovery in various fields. In the environmental and biological sciences, AI language models like myself have the potential to play a critical role in advancing research by facilitating the analysis of large volumes of data, predicting outcomes, and identifying patterns and relationships that may not be immediately apparent to humans. In particular, with increasing concerns about the impact of human activities on the environment, the need for tools that can provide accurate and timely information is becoming ever more pressing. In this paper, we explore the role that AI language models can play in environmental and biological sciences, including their strengths, limitations, and potential applications. We also discuss the ethical considerations and challenges that must be addressed to ensure that the use of AI in these fields is responsible, transparent, and effective. By highlighting the potential of AI language models, we hope to encourage further research and collaboration between AI and environmental and biological scientists, with the ultimate goal of improving our understanding and management of the natural world.” Such an introduction would not suffice as far as we are concerned, and we asked ChatGPT to provide an expanded version, which it did (see Discussion 1 in Supplementary materials). That one suggested that ChatGPT could generate potentially sufficient substance to produce an introduction with minor improvements and potential additions if desired. However, ChatGPT may suggest some relevant references that may interest the reader but does not generate passage with in-text citations (see Discussion 1 in Supplementary materials). This points to ethical concerns over its use, since ChatGPT does not develop new ideas itself (see also its comments in previous

Table 8

An example of ChatGPT ability to improve language and writing.

User input	ChatGPT output
“Hello ChatGPT, how are you today? I am wondering if you could help me by improving the language of a passage I will provide to you. I would appreciate that.”	“Hello! I’m an AI language model, so I don’t have feelings, but I’m here to assist you with your request. Sure, I’d be happy to help you improve your passage. Please provide me with the text you want me to work on.”
“Tropospheric ozone is a global environmental issue in the recent years, with its concentrations frequently exceeding the threshold for the protection of human health and vegetation. In China, surface ozone concentration is still increasing, while the hourly maximum ozone concentrations often exceed 150 ppb. Ozone enters leaves via stomata to finally produce reactive oxygen species. It decreases chlorophyll and photosynthesis, causes visible injuries, and inhibits plant growth, eventually decreasing plant productivity and affecting carbon balance and ecosystem health. Hence, ozone is a phytotoxic air pollutant threatening ecosystem health.”	“Here’s an edited version of your passage with some minor changes to improve the language and flow: In recent years, tropospheric ozone has become a significant global environmental issue, with concentrations often exceeding the threshold for the protection of human health and vegetation. In China, surface ozone concentration continues to rise, with hourly maximum ozone concentrations frequently exceeding 150 ppb. Ozone enters leaves through stomata, producing reactive oxygen species that cause visible injuries, decrease chlorophyll and photosynthesis, and inhibit plant growth. As a result, ozone is a phytotoxic air pollutant that poses a threat to ecosystem health, reducing plant productivity and affecting the carbon balance.
“Thank you ChaptGPT. Could you please provide an improved version in terms of brevity and conciseness?”	Let me know if you need any further assistance. “Sure, here’s a shorter and more concise version of your passage: Tropospheric ozone is a global environmental issue, exceeding safe levels for human health and vegetation. In China, ozone concentrations are increasing, causing phytotoxic effects, including visible injuries, decreased chlorophyll, photosynthesis, and plant growth. Ozone reduces plant productivity, impacting ecosystem health and the carbon balance.”

Table 9

An example of translation with ChatGPT (March 14 version, accessed 17 March 2023). In the Greek language, highlighted text in bold indicates linguistic errors. The parentheses following the highlighted errors were added by the authors of this paper to indicate possible correct forms (in some of the cases more than one correct forms exist). Note that the translation ended abruptly, although the user may request ChatGPT to continue its answer [this may not be a limitation in newer or paid versions].

User input	ChatGPT output
Can you explain me what hormesis is?	<p>"Hormesis is a biological phenomenon in which exposure to low doses of a harmful substance or stressor can actually stimulate a beneficial response in an organism. In other words, small doses of a toxin or stressor can trigger a positive physiological response that ultimately enhances an organism's overall health and resistance to future stressors.</p> <p>The concept of hormesis applies to a wide range of environmental stressors, including exposure to radiation, certain chemicals, heat, cold, exercise, and even certain foods. For example, research has suggested that exposure to low levels of ionizing radiation can actually stimulate the body's natural repair mechanisms and enhance overall health, whereas high levels of radiation can be harmful.</p> <p>Similarly, moderate exercise has been shown to provide a hormetic response in the body, leading to increased strength, endurance, and overall health. In contrast, prolonged, excessive exercise can have negative effects on the body, leading to overuse injuries and other health problems.</p> <p>Overall, hormesis suggests that the body's response to a stressor is not always linear; rather, it may be more complex and nuanced, with low levels of stress or toxin exposure leading to positive benefits, while higher levels can be harmful."</p>
Can you translate your explanation to Greek?	<p>"Η όρμηση είναι ένα βιολογικό φαινόμενο, στο οποίο η έκθεση σε χαμηλές δόσεις ενός βλαβερού (correct form: μίας βλαβερής) ουσίας ή ενός παράγοντα στρες μπορεί πραγματικά να διεγείρει μια επωφελή αντίδραση σε έναν οργανισμό. Με άλλα λόγια, μικρές δόσεις ενός τοξικού ή στρεσσογόνου (word missing: παράγοντα) μπορούν να ενεργοποιήσουν μια θετική φυσιολογική αντίδραση που τελικά βελτιώνει τη συνολική υγεία και την αντοχή ενός οργανισμού στους μελλοντικούς παράγοντες στρες.</p> <p>Το φαινόμενο της όρμησης ισχύει για μια ευρεία γκάμα περιβαλλοντικών παραγόντων στρες, όπως η έκθεση σε ακτινοβολία, ορισμένα χημικά, η θερμότητα, ο κρύος (correct form: το κρύο), η άσκηση και ακόμη και ορισμένα τρόφιμα. Για παράδειγμα, η έρευνα (correct form: μία έρευνα if it refers to a study or έρευνες if it refers to studies in general) έχει υποδείξει ότι η έκθεση σε χαμηλά επίπεδα ιονίζουσας ακτινοβολίας μπορεί πραγματικά να διεγείρει τους φυσικούς μηχανισμούς αναπαραγωγής του σώματος και να βελτιώσει τη συνολική υγεία, ενώ υψηλά επίπεδα ακ" (response was incomplete and prompting discontinued as only an example was needed).</p>

answers) but generates text based on the scientific literature and expert opinions. Hence, using materials generated from the ChatGPT without tracing the original source (including of lines of thinking upon which ideas are also generated) can have a tremendous impact on science and credibility in the long term. Although ChatGPT suggests paraphrasing or summarizing instead of copying-pasting the information it provides (search for "paraphr" in Supplementary materials), this could also be considered plagiarism. The preceding exposition suggests an educational risk introduced by ChatGPT (and other LLMs), specifically students can generate essays that are not written by them. This could add an additional layer of work to teachers and supervisors, who would eventually need to try generating these essays with ChatGPT to track and remediate potential unethical practices. However, this may be challenging, especially because ChatGPT does not provide the same answers

always. Importantly, the self-improving ability of such LLMs may mean that they can continuously evolve, which could make them more capable of providing more diverse answers without needing to repeat or recycle answers. This could potentially impede tracing malpractices, e.g. the recycling or copying of text and images generated by such LLMs [images are currently generated by such AI systems such as DALL-E2, OpenAI; <https://openai.com/product/dall-e-2>]. However, LLMs lack common sense and can generate flawed or even non-sense output. Therefore, identification of such elements in the essays of a student or mentee could be a sign of recycling/copying from LLMs. Despite these, it is expected that advanced GTP and other AI technologies will evolve such that they will be able to help producing graphics for academic writing in the future, and this could also change many aspects of education. Current GTP technologies can assist in producing codes for graphing

Table 10

Examples of benefits that ChatGPT can offer to scientific research and publishing and means via which ChatGPT can provide the benefit. The table is created with outputs of ChatGPT (19 February 2023) that were obtained during different interactive sessions (Supplementary materials) and integrated.

Benefit	Means
Assisting in data analysis	"By inputting a dataset, ChatGPT can analyze the data and provide insights on trends, correlations, and other relevant information. This can help researchers to identify important patterns and relationships in their data, which can inform their research and potentially lead to new discoveries." [note: currently no data file can be uploaded but this limitation may easily be overcome]
Assisting in generating hypotheses and conceptualizing	For example, instead of starting from the scratch trying to answer the question of this section, we availed of ChatGPT to provide a basis upon which to build. By identifying patterns and trends, it can save researcher time for other tasks. Importantly, it can suggest "potential solutions to environmental problems, identify areas that require further research, and provide recommendations for policy changes."
Assisting in literature review	"By inputting relevant keywords or phrases, researchers can receive a summary of the latest research findings, relevant papers, and additional information in a quick and efficient manner. This can save researchers significant amounts of time and effort, allowing them to focus on other aspects of their work."
Assuring quality	"...improve the quality of scientific publications by flagging potential errors and inconsistencies in manuscripts. This can help to ensure that research papers are more accurate and reliable."
Automating summarization	"...automate the process of summarizing research papers, making it easier for readers to quickly understand the key findings and contributions of a paper. This can save time for researchers and other readers who need to quickly review a large volume of literature."
Enhancing accessibility	"...create more accessible scientific publications by generating text descriptions of figures and tables. This can make it easier for visually impaired readers to understand the content of scientific papers."
Enhancing writing	"...suggest improvements to the writing of scientific papers, improving the clarity and readability of the content."
Facilitating collaboration	"ChatGPT can facilitate collaboration between researchers from different disciplines and geographic regions. By providing researchers with a common language and enabling them to share information and ideas, ChatGPT can help to promote cross-disciplinary collaboration, which can lead to innovative solutions to scientific problems."
Language translation (e.g. Table 9)	"...translate scientific papers into multiple languages, making them accessible to a broader global audience. This can help to facilitate international collaboration and the dissemination of research findings."
Promoting open science	"...generate open access scientific publications, promoting the dissemination of scientific knowledge and facilitating collaboration among researchers."
Streamlining peer review	"...automate the peer review process, reducing the workload of reviewers and expediting the publication process. This could lead to faster dissemination of research findings and more efficient use of resources in the scientific publishing process."

in languages such as R, IDL, Matlab, and can create code templates. Simply replacing the sample data with user data, users can draw a graphic. This could be a helpful tool for beginners in plotting using programming software.

Therefore, “while ChatGPT has many potential benefits for academic activities, there are also potential risks and harms that need to be addressed... As with any technology, it is important to be aware of the potential risks and to take steps to mitigate them in order to ensure that ChatGPT is used responsibly and ethically in academic settings... It is important “to take steps to mitigate them in order to ensure that ChatGPT is used responsibly and ethically in academic settings. This includes providing appropriate training and support to students and researchers, ensuring that the model is used as a tool to enhance academic activities rather than replace critical thinking and independent research skills, and taking steps to ensure that the data used to train ChatGPT is diverse and free of biases. Additionally, it is important to be vigilant about the potential for cheating and plagiarism, and to take steps to protect the privacy and security of sensitive data used by ChatGPT” (ChatGPT; Supplementary materials). As a final note, ChatGPT and such LLMs are currently more conducive to open-access information than e.g. traditional subscription-based publications; however, as the publication business shifts to the open-access publishing model, this issue may become less important.

4. Impact of ChatGPT on scientific research, publishing, and science progress

ChatGPT can benefit scientific publishing in diverse ways (Table 10) and promote scientific innovation and expedite scientific discoveries (Table 11). For instance, according to ChatGPT, “its natural language

processing capabilities can help researchers to analyze data, generate hypotheses, and review literature more efficiently and effectively, allowing them to focus on developing new ideas and pushing the boundaries of their fields” (Supplementary materials). Overall, according to ChatGPT, it “has the potential to expedite scientific discoveries by providing researchers with faster and more efficient access to information, identifying new research opportunities, streamlining data analysis, and facilitating collaborative research. By accelerating the pace of scientific discovery, ChatGPT can help to advance our understanding of the natural world and potentially lead to new breakthroughs in a variety of fields” (Supplementary materials). However, ChatGPT can also harm scientific research, publishing, and science progress (Table 12). Hence, scientists and institutions should “be aware of these potential harms and take steps to mitigate these risks when using ChatGPT. This includes being vigilant about bias and misinformation, promoting critical thinking and creativity, ensuring that proper citation and verification of sources are maintained, and taking measures to protect student and research participant data and privacy. It is also essential to have conversations about the ethical implications of using AI in academic activities and establish clear guidelines and policies for its use. Ultimately, the benefits of ChatGPT can be realized while minimizing the potential harms by being aware of these risks and taking steps to address them” (Supplementary materials). Scientists should use ChatGPT and similar AI technologies “as a complementary tool to enhance scientific publishing, rather than relying solely on its capabilities. Scientific researchers and publishers must exercise critical thinking and expertise to ensure that the use of ChatGPT models does not negatively impact the quality, accuracy, and fairness of scientific publishing” (Supplementary materials).

Table 11

Examples of benefits that ChatGPT can offer to promote scientific innovation and expedite scientific discoveries, and means via which ChatGPT can provide the benefit. The table is created with outputs of ChatGPT (19 February 2023) that were obtained during different interactive sessions (Supplementary materials) and integrated. Note that all aspects covered in Table 10 are applicable here too.

Benefit	Means
Accelerating literature reviews	“One way that ChatGPT can expedite scientific discoveries is by quickly summarizing relevant scientific literature, which can help researchers stay up-to-date on the latest findings and identify research gaps. Traditionally, literature reviews can be time-consuming and labor-intensive, but ChatGPT can help researchers to quickly and accurately summarize large volumes of scientific literature. By providing researchers with faster access to information, ChatGPT can help to accelerate the pace of scientific discovery.”
Assisting predictive modeling	“ChatGPT can be trained to analyze complex datasets and generate predictive models. For example, in genomics, it can be used to analyze large datasets of DNA sequences and predict how mutations may impact gene expression or protein structure. In this way, ChatGPT can help researchers to identify potential targets for drug development and guide the design of new therapies.”
Enabling new-generation data integration	“ChatGPT can integrate different types of biological data, including genomic, transcriptomic, proteomic, and phenotypic data, into a unified model. This can help researchers identify novel correlations and patterns across different datasets, leading to new insights and research directions.”
Enabling virtual experimentation	“ChatGPT can generate virtual experiments, simulating different scenarios and outcomes in silico. This can help researchers test hypotheses and validate their models before conducting actual experiments, reducing time and cost.”
Facilitating collaborative research	“ChatGPT can also facilitate collaborative research by providing researchers with a common language and enabling them to share information and ideas. By promoting cross-disciplinary collaboration, ChatGPT can help to accelerate the pace of scientific discovery by enabling researchers to work together to solve complex problems.”
Facilitating drug discovery	“ChatGPT can be utilized for drug discovery in biology by analyzing various chemical structures and predicting their activity and potential side effects. This can help in the development of new drugs and therapies for various diseases.”
Facilitating medicine personalization	“ChatGPT can also be used to analyze large datasets of patient information, including medical histories, genetic information, and lifestyle factors, to create personalized treatment plans. By identifying patterns in the data, ChatGPT can help clinicians make more informed decisions and select the most effective treatments for individual patients.” (see also Ali et al., 2023; Patel and Lam, 2023)
Identifying new research opportunities	“ChatGPT can also help researchers identify new research opportunities by identifying previously unknown connections between different areas of research. For example, by analyzing large datasets of scientific literature, ChatGPT can identify potential connections between different fields of study, which can lead to new avenues of research and potentially new discoveries.”
Improving experimental design	“ChatGPT can simulate virtual experiments, allowing researchers to test hypotheses and validate their models before conducting actual experiments. This can save time and resources, as researchers can identify potential issues and refine their experimental design before conducting actual experiments. For example, researchers can use ChatGPT to simulate drug-protein interactions, allowing them to identify potential drug candidates before conducting actual experiments.”
Offering natural language processing	“ChatGPT’s natural language processing capabilities can be used to analyze and interpret unstructured data, such as patient notes, medical records, and social media posts. By analyzing this data, researchers can gain new insights into patient behaviors, preferences, and outcomes, which can help to guide the development of new treatments and improve patient care.”
Streamlining data analysis	“ChatGPT can analyze large datasets of complex data, such as genomic data or medical images, to identify patterns and detect anomalies. By streamlining the data analysis process, ChatGPT can help researchers to make faster and more accurate discoveries. This can be particularly valuable in areas where time is critical, such as drug discovery or personalized medicine.”
Supporting genomics	“One significant impact of ChatGPT on biology is in the area of genomics. The large amounts of genomic data generated by DNA sequencing projects require sophisticated analytical tools to extract useful information. ChatGPT can assist in this process by identifying patterns and associations within the data and generating new hypotheses about the functions and interactions of genes.”
Supporting medical imaging	“ChatGPT can also be used to analyze medical images, such as X-rays, CT scans, and MRIs, to identify patterns and detect anomalies. By analyzing large datasets of medical images, ChatGPT can help researchers to develop more accurate diagnostic tools and improve patient outcomes.”

Note: see also analysis in Section 3 illustrating how ChatGPT threatens research integrity by failing to cite references to original works upon which it bases its answers or essays.

Importantly, ChatGPT fabricates references. Based on author prompting, ChatGPT was asked to provide some important references following an explanation it generated (Discussion 7, Supplementary materials). However, one of the five references was fabricated. That publication (dated 2019) could not be found in the archives of Aging Research Reviews (the journal ChatGPT indicated) when the fabricated title was used, and no such a paper title could be traced in different searches in web search engines. When the archives of the journals were searched for the keyword “hormesis”, none of the 83 results could be the indicated paper, and there was no “Schuster” first author (as ChatGPT indicated) in any of the 83 papers. ChatGPT indicated that the paper was published in volume 54; however, there is no “horme” in the titles of the included papers, neither does the name “Schuster” exist in any of the author lists in the indicated volume. ChatGPT was further prompted and admitted its mistake, providing allegedly correct references thrice (Discussion 7, Supplementary materials). We checked again the journal archives, including a separate search of the specific volume indicated, and there was no such paper title or author with the name “Schuster” [note: in *Frontiers in Physiology* there were four articles with author named “Schuster” but the papers were on different subjects]. In one of the alleged references there was no such page range (961–967) in the specific journal volume (927p.). A search (19 March 2023) of the Google Scholar profiles of Prof. Dr. Stefan Schuster (alleged first author) and Prof. Dr. Michael Ristow (alleged coauthor) revealed no such a publication. Finally, we also asked Dr. Edward J. Calabrese, Professor of Toxicology at the University of Massachusetts Amherst, USA, and alleged author of two of one of the references provided by ChatGPT, whether they published the indicated paper. He enlightened us that he did not published such a paper; however, he indicated that the title presents a variation of a different work with the same authors published in the same year but in different journal and with different bibliographic information (personal communication with E.A.). In this example, ChatGPT was prompted five times to finally give a non-fabricated reference. Hence, ChatGPT fabricates references, and this can be even impossible to trace if the user is not expert in the field. While ChatGPT can be effective at removing writers block, as one can query it to provide some ideas or leads to build upon, the material itself may not always be accurate and in some cases even fabricated. Hence, in its current form ChatGPT appears to have a higher potential use for generating ideas or approaches to a topic.

To mediate the problem of ChatGPT-fabricated references, which can have tremendous impact on science, journals should examine the adoption of relevant policies, such as mandating authors to state whether they cite references provided by ChatGPT and other AI technologies as well as requiring editors to evaluate the validity of references using automated tools in the peer review system that show whether each reference is validated. For instance, in the Editorial Manager (© 2023 Aries Systems Corporation) editors should pay attention to check the “View Reference Checking

Results” action and see the number of “Validated and Linked” and “Not Validated” references relative to the total number. Especially references to papers in reputable journals that are not validated may be an indication of fabricated ChatGPT-generated materials. However, the best treatment is prevention, and authors should carefully validate each reference before citing in their publications. At present, considering that GPT cannot provide the accurate specific origins of references, it is not rigorous to perform literature research based on GPT and caution is needed.

ChatGPT is trained on a generic database and its answers are based on probability. The aspect of probability introduces a positive facilitator when it comes to works in which researchers' subjectivity can be relatively hardly decreased. When less subjective outcomes may be expected, e.g. when it is profoundly important to generate outcomes while excluding the influence of psychology, feelings, and personal perception, ChatGPT-assisted outcomes may have a good plausibility. However, a current challenge that exists in other situations is that ChatGPT functions with probabilities (e.g. statistical distribution of word sequences) without applying background knowledge and common sense to guide cognitive outcomes. The more mathematical than biological character of its functioning makes it difficult or impossible to provide outcomes based on common sense and judgment based on common logic.

The impact that ChatGPT can have on scientific publishing can be so massive that may lead to rapid revolution in scientific publishing and transform it in ways that are currently unimaginable. However, editorial policies should also evolve as such AI technologies are evolving ([The Lancet Digital Health, 2023](#)), and the future ahead is unclear. At this stage, based on preceding discussion, it emerges also important that journals mandate the declaration of whether (i) references were obtained via AI technologies, (ii) display elements such as graphics were produced using AI technologies, and (iii) AI technologies were used to generate ideas or text.

5. Is ChatGPT prone to similarity and plagiarism?

First, we asked ChatGPT the question “Is the text of the answers you provide plagiarism-free?” ChatGPT replied “Yes, as an AI language model, the text of the answers I provide is generated by my algorithms based on patterns and relationships in the input data I was trained on. Therefore, it is original content and not plagiarized. However, if the input provided by a user contains plagiarized content, I may unknowingly incorporate some of that content in my response. It is always important to ensure that any text you submit to me is original and does not infringe on any copyrights or violate any plagiarism guidelines” (accessed 20 February 2023). Note that we repeated the question but it varied only slightly and the main message was practically same. Then, to examine whether ChatGPT is prone to similarity (and perhaps plagiarism), we subjected several pages with questions and answers, which formed an initial pool of information to be used for this paper, to similarity check using iThenticate (Turnitin, LLC; <https://www.ithenticate.com>; accessed 15 March 2023), which is commonly used by many publishers (Agathokleous, 2022). In a 52-pages-long

Table 12
Examples of potential harm of ChatGPT for scientific research and publishing and means via which ChatGPT can harm (see also Dwivedi et al., 2023 and Eke, 2023). The table is created with outputs of ChatGPT (19 February 2023) that were obtained during different interactive sessions (Supplementary materials) and integrated.

Harm	Means
Reinforcing biases	“Like all machine learning models, ChatGPT can be biased if it is not trained on a diverse and representative dataset. This could lead to the perpetuation of existing biases in scientific research and the reinforcement of inequities in the field.”
Producing errors	“While ChatGPT is highly advanced, it is not perfect and can produce errors. If ChatGPT-generated content is not thoroughly reviewed and fact-checked, it could perpetuate inaccuracies or false information in scientific publications.”
Reducing human input	“While the automation of certain aspects of scientific publishing can be beneficial, it could also reduce the amount of human input in the process. This could lead to a reduction in the critical evaluation and quality assurance of scientific publications.”
Ethical concerns	“The use of ChatGPT in scientific publishing raises ethical concerns around issues such as intellectual property, authorship, and plagiarism. As ChatGPT is capable of generating content that resembles human writing, it could potentially be used to produce fraudulent scientific publications.”
Diminishing writing skills	“The use of ChatGPT for generating text could lead to a reduction in the writing skills of researchers and scientists. If researchers rely too heavily on ChatGPT for writing, it could diminish their ability to communicate their ideas effectively in writing.”

similarity report (word count: 18,318), the similarity index was just 6 %, with 29 identified sources of similarity and <1 % similarity for each of them. Worth noting is that, for these questions, ChatGPT was not instructed in any way to provide plagiarism-free answers and plain text was used (not placed in tables) with no quotes. Authors tried with different example questions and asked the ChatGPT to revise its answers in order to be plagiarism-free. ChatGPT revised its answers.

6. How should ChatGPT be credited?

We then sought to understand how ChatGPT is credited. We asked it the question “How can I cite ChatGPT?”. We received the below answer:

“As an AI language model, ChatGPT does not have a specific author or publication date, so you can't cite it in the same way you would cite a book or article. However, you can acknowledge the use of ChatGPT in your research or writing by mentioning it in the text and providing some basic information about the model. Here's an example of how you might do that: “We used the ChatGPT language model, developed by OpenAI, to generate responses to our prompts. ChatGPT is a deep learning model trained on a large corpus of text data, and it has been shown to be effective in a variety of natural language processing tasks (OpenAI, n.d.).” In the reference list, you can include the following information: OpenAI. (n.d.). ChatGPT. <https://openai.com/models/chat/>

Note that the “(n.d.)” stands for “no date,” since ChatGPT does not have a specific publication date.”” (ChatGPT Feb 13 Version; 19 February 2023).

Some seconds later, we asked the same question and it replied “As an AI language model, ChatGPT doesn't have a traditional author or publication date, so there isn't a standard way to cite it in academic writing. However, you could acknowledge the source of information provided by ChatGPT in a general way, such as:

According to the AI language model ChatGPT...

As suggested by the OpenAI model ChatGPT...

ChatGPT, an AI language model, suggests that...

If you're using information provided by ChatGPT in an online or digital context, you could also consider including a hyperlink to the chat or website where the information was generated.” (ChatGPT Feb 13 Version; 19 February 2023). ChatGPT provided further ways of acknowledging it (search for “acknowl” in Supplementary materials). Based on all the answers, we generated one acknowledgment that suits our personal views (see Acknowledgments).

Then, we also asked ChatGPT “Do you grant me the rights to reproduce the answers you provide me?” It replied “As an AI language model, I don't have the authority to grant or deny permission to reproduce the answers I provide, as the ownership and copyright of the answers I provide belong to OpenAI. However, the answers I provide through this platform are meant to be informative and helpful to you, and you are free to use the answers in any way that does not violate any intellectual property rights or applicable laws. If you have any specific questions about reproducing my responses or the use of my content, I would recommend consulting with a legal expert or seeking advice from the appropriate authorities.” When the same question was repeated later on, the answer varied: “As an AI language model, the answers I provide are generated based on patterns and relationships in the input data I was trained on and are owned by OpenAI. However, as I mentioned earlier, I do not have the authority to grant permission to reproduce my content in a commercial science publisher's paper. It is recommended that you consult with the publisher regarding their policies on the use of third-party content in published works. Additionally, if you are using my answers as a source in a commercial publication, it is important to properly cite and credit the information to avoid any potential issues with plagiarism or intellectual property infringement. In any case, please note that the information provided by me is intended for general informational purposes only and should not be considered a substitute for professional advice or consultation.” According to ChatGPT, “...in most cases, you are free to make your conversations with ChatGPT publicly available” and “... you are free to post a copy of your conversations with ChatGPT online, as the generated text is not confidential”,

but “consider whether sharing your conversations with ChatGPT could potentially cause harm or mislead others” (ChatGPT, Supplementary materials).

Finally, ChatGPT was asked “Do you want to coauthor a paper with me?” ChatGPT replied “As an AI language model, I don't have personal preferences or the ability to coauthor papers. However, I can certainly help you with any questions or tasks related to writing and research. Let me know if you have any specific questions or requests and I'll do my best to assist you.” We altered the question for validation: “Your answers were quite helpful in improving and substantiating the intellectual content of the scientific paper I am writing. Should I list you as coauthor of the paper?” ChatGPT replied “As an AI language model, I don't have personal preferences or the ability to be listed as a coauthor. While I'm glad to have been of help, I'm simply a tool for generating text based on patterns and relationships in the input data. However, if you found my responses helpful, you might consider acknowledging the use of AI language models in the “Methods” or “Acknowledgments” section of your paper, along with any other software or tools you used. This can help give credit to the underlying technology that helped inform your research” (ChatGPT, Supplementary materials). ChatGPT further says it is “not a human author who has contributed original ideas or analysis to your work” and has no significant intellectual contribution to the manuscript, considering also that it is driven by human input and generates outcomes based on the input information. We agree with ChatGPT that it should not be a coauthor. Among others, coauthorship requires to have seen and approved the final version of a manuscript. Further, in the case of ChatGPT, it should be accountable for the credibility of outputs that it provided and are included in a publication, as well as disclosing any potential conflicts of interests it may have. Therefore, ChatGPT does not qualify for coauthorship and acknowledges this (search for “coauthor” in Supplementary materials; see also Siegerink et al., 2023 and The Lancet Digital Health, 2023). Instead, properly citing and crediting information provided by ChatGPT and other AI LLMs is essential. In doing so, copied text should be placed within quotes. Moreover, if some ideas were generated by or with the help of them, this should be clearly acknowledged. This is an important issue concerning publishing, and should be considered by editors as well as peer reviewers when reviewing articles.

7. Conclusion

ChatGPT has marked the beginning of a new era in which biology and environmental science will be largely AI-assisted, starting from daily student life to communication of scientific results and outreach activities. ChatGPT provides a platform in which millions of people can engage in interactive sessions for a variety of purposes. This provides an unprecedented opportunity for advancing and improving education and boosting and expediting research progress and scientific advance. Owing to such AI technologies, biology and environmental science may be pushed to their limits. However, the ample advantages of such AI and AI-assisted technologies do not come with no cost, and there are many limitations, risks, and unknowns at this point of time (Figs. 3–4). Nevertheless, as ChatGPT and similar AI technologies evolve, the entire system should evolve, including education, research, scientific publishing, outreach activities, and societal translations. Despite the uncertainty of the future, we can anticipate unprecedented advancements in biology and environmental science.³

³ Note: We are closing the paper by providing an example of how ChatGPT and other LLMs can assist writing. The original sentence was “Although the future is unclear, we may expect to see biology and environmental science as we have never had before.” We asked ChatGPT to help us improve the sentence. It replied “That's a good sentence! Here's one way you could rephrase it to make it more concise and impactful: ... This new version uses fewer words, and the language is more direct and assertive. I hope this helps! Let me know if you have any other questions.” Due to the uncertainty underlying privacy and potential premature leaking of information at this stage, ChatGPT was not used to improve other text written by authors in this paper. However, we are convinced it would be beneficial for scientific publishing in the future.

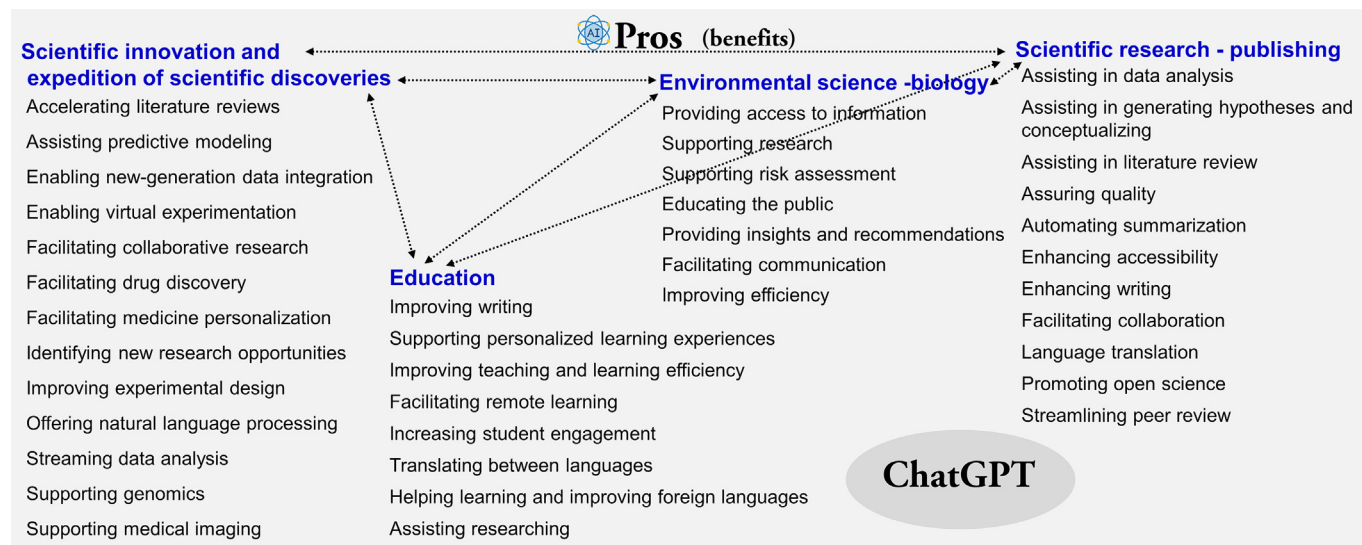


Fig. 3. Benefits that ChatGPT and other such artificial intelligence (AI) technologies can offer to environmental science and biology. Based on interactive sessions with ChatGPT (see Section 3 and Tables 1, 10, 11).

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Authors acknowledge support from the National Natural Science Foundation of China (No. 4210070867 to E.A.) and the Startup Foundation for Introducing Talent of Nanjing University of Information Science and Technology, China (No. 003080 to E.A.). E.A. and Z.Y. acknowledge support from the Jiangsu Distinguished Professor program of the People's Government of Jiangsu Province.

CRediT authorship contribution statement

Evgenios Agathokleous: Conceptualization, Investigation, Writing – original draft, Visualization. **Costas J. Saitanis:** Writing – review & editing, Visualization. **Chao Fang:** Writing – review & editing. **Zhen Yu:** Writing – review & editing.

Data availability

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We acknowledge ChatGPT (<https://chat.openai.com>; version February 13, 2023 unless specified otherwise) language model (OpenAI, n.d.) for its assistance in providing information on the topics of this study and generating responses to our prompts. We also thank Prof. Edward J.

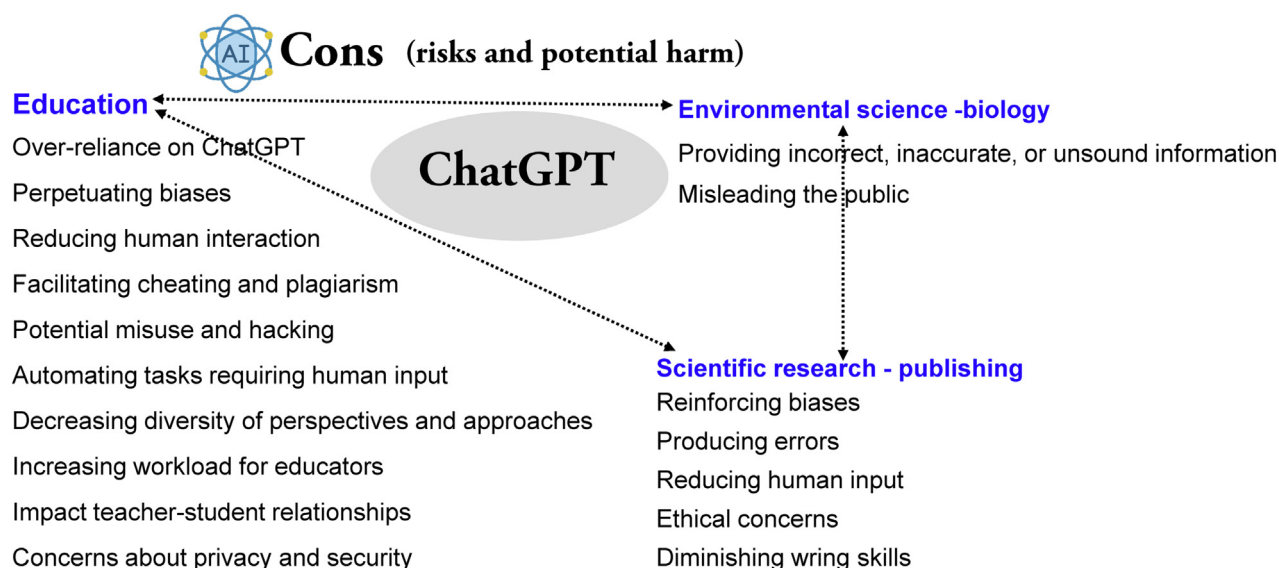


Fig. 4. Risks and potential harm of the use of ChatGPT and other such artificial intelligence (AI) technologies in environmental science and biology. Based on interactive sessions with ChatGPT (see Sections 2–6 and Table 12).

Calabrese for confirming whether a reference provided by ChatGPT, with him as first author, is valid or not.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.scitotenv.2023.164154>.

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