



Academic integrity and artificial intelligence: is ChatGPT hype, hero or heresy?

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Academic integrity in both higher education and scientific writing has been challenged by developments in artificial intelligence. The limitations associated with algorithms have been largely overcome by the recently released ChatGPT; a chatbot powered by GPT-3.5 capable of producing accurate and human-like responses to questions in real-time. Despite the potential benefits, ChatGPT confronts significant limitations to its usefulness in nuclear medicine and radiology. Most notably, ChatGPT is prone to errors and fabrication of information which poses a risk to professionalism, ethics and integrity. These limitations simultaneously undermine the value of ChatGPT to the user by not producing outcomes at the expected standard. Nonetheless, there are a number of exciting applications of ChatGPT in nuclear medicine across education, clinical and research sectors. Assimilation of ChatGPT into practice requires redefining of norms, and re-engineering of information expectations.

Semin Nucl Med 53:719-730 © 2023 Elsevier Inc. All rights reserved.

Introduction

Contract cheating (commercial ghost-writing) has attracted considerable attention in the media and higher education literature in recent times. While contract cheating is not a new concept, outsourcing academic assessment for payment to a third party has become more prevalent or perhaps efficient with advances in information technology.¹ The disruption to on-campus studies due to COVID-19 saw a rapid transition to digital learning and assessment platforms which increased the opportunity for contract cheating.² The COVID-19 driven change to online learning in school and university learning drew considerable attention to AI misuse and academic integrity concerns.^{3,4} At the core of the issue is potential reputational damage to institutions, professions and the sector, and public safety if graduates do not genuinely develop the requisite skills and capabilities.⁴ This is not a concern unique to educational institutions with academic integrity also challenged

by AI in the scientific community. For example, fabricated abstracts have been regularly accepted through review processes for professional conferences⁵ and a quanta of AI-generated, fabricated journal articles have passed peer review and been published.⁶

There was little discussion of ChatGPT (just 5 articles in Medline in 2022) yet an explosion of literature since ChatGPT was publicly released on November 30, 2022 (163 articles in Medline in the first quarter of 2023 and 273 articles by 20 April 2023). Less than 2 months after launch, ChatGPT had over 100 million users.⁷ Universities and schools have reacted to rapid adoption of ChatGPT, in many cases applying blanket bans to its use⁸; attempting to protect against misuse while forgoing potential education benefits. Yet AI augmentation of student learning is not limited to ChatGPT. Grammarly and similar AI tools have been assimilated into student learning to correct and refine writing without this level of debate around academic integrity. Rather than regulating the use of AI tools, perhaps it is an opportunity to re-engineer learning and assessment.

In the health domain, the key debate is centered on benefits (eg, research, writing and problem solving) vs misuse (scientific fraud, cheating, academic integrity). Indeed, the generative nature of ChatGPT allows fabrication of entire

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scientific abstracts that avoid both plagiarism detection and identification through human review.⁹ This comes at the cost of potential error (hallucination) and fabrication of both information and citations. A key concern is the rapid emergence where implementation and applications have assimilated into clinical, research and academic cultures in the absence of regulatory, educational or ethical guidelines and frameworks. In particular, there is a pressing need for development of ethical guidelines for use of ChatGPT and other AI tools for learning, enhancing capabilities, research, writing, and assessment. Not dissimilar to the issues of developing ethical guidelines for AI use generally in medical imaging in parallel to implementation.^{10,11} Like AI in medical imaging, an early hype phase saw widespread use of AI “if we can, let’s do it” which quickly devolved to a more focused approach to areas of actual benefit “just because we can, does not mean we should.” Nonetheless, a systematic review of ChatGPT in health revealed strong perceptions of benefits to academic and scientific writing (followed by scientific research benefits) while ethical issues predominated risks and concerns (followed by inaccuracies).¹² These concerns perhaps reflect general AI concerns.

The role of AI tools in education and scientific writing, especially ChatGPT, has been the topic of broad discussion, including in social media. Perhaps “artificial intelligence” would be better expressed as “augmented intelligence” or “engineered learning.” Several personal anecdotes provide an important context for further discussion. The first is a good friend and physician / radiologist who was using ChatGPT to more deeply interrogate the content being taught in post-graduate class and to enrich their note taking. They posed the question in social media whether students should use tools like this to enhance their educational experience, including continuing education and continuing professional development. My response suggested that where AI enhances education, it should be supported but where AI is used to mask a lack of learning or to create evidence of learning that did not really occur, it should not be acceptable. This creates an ambiguous region associated with AI augmenting of a learner’s capability. Perhaps an important question relates to equity where some learners will have access to ChatGPT while others may not; creating a disparity in learning opportunity and skill development. Again, a similar issue to *social asymmetry* of use and benefits for AI generally in medicine and health.¹³ One should also keep in mind that for rapidly advancing industries like nuclear medicine, at the time of writing public access was only available to ChatGPT powered by GPT-3.5 whose learning cut-off date was September 2021. This limits insights into new and evolving innovations and knowledge. ChatGPT is a language model with no real-time access to information and it also does not browse the internet. While ChatGPT can respond through conversation, it does not use one conversation or input to inform that of another. Furthermore, distinction should be made between information with the skill to present it (ChatGPT), and knowledge with the capability to apply it (competent human).

Many universities have imposed a blanket ban on ChatGPT but this perhaps creates further inequity because of the difficulties policing such policies; particularly in open book, noninvigilated, online exam environments. Another consideration relates to authentic assessment; assessing student knowledge and skills in a manner that closely resembles how they might use those same knowledge and skills in the real world after graduation. If ChatGPT has emerged as a tool for use among nuclear medicine professionals in the clinical and research environment, should assessment not afford that same environment? For example, another social media conversation with international colleagues (physicist) revealed use of ChatGPT to craft sections of journal articles. This might reflect writing an entire section or it might be used to enhance pre-existing text written by the author. Authors need to be cognisant of the boundaries between plagiarism and authorship and the discussion mused at the potential h-index of ChatGPT as a coauthor of journal articles. Entire assignment drafts, theses, or journal manuscripts could be lifted into ChatGPT for fact checking, improving grammar and spelling, and improving writing style. This could readily represent either powerful learning opportunities or a threat to academic and scientific integrity. For example, a poorly crafted PhD dissertation unlikely to pass could be re-engineered by ChatGPT, including fabrication of evidence, and submitted for successful examination. Conversely, an excellent piece of doctoral research shackled only by a language barrier could be presented more appropriately for the examination the work deserves and might otherwise miss. Indeed, some academics have enormous publication outputs on the basis of being the language conversion writer for non-English language research teams; a role potentially made redundant by ChatGPT. Does language conversion warrant inclusion as an author, for human or AI input? For medical and health education, ChatGPT could provide realistic scenarios for case-based learning, customize learning for a user’s weaknesses (or strengths), help interpret, understand or distil complex learning topics (eg, from textbooks or lectures), and summarize a volume of literature (eg, medical literature reflecting latest developments from one or more journals).⁷

AI enabled scientific fraud is an important issue in nuclear medicine, radiology and the broader medical literature. Generative AI algorithms can be used to produce fictitious data, images or entire reports; *deep fakes*. While it is possible for authors to simply substitute a real medical image that represents the message or results they want to convey, Gu et al¹⁴ reported that generated images are harder to detect as fake than substitution of real images. Generative adversarial networks (GANs) are deep learning, encoder-decoder algorithms that can be used to produce de-noising of medical images, image reconstruction and create digital twins for radiation dosimetry¹⁵ or preclinical research,¹⁶ but can be used to generate synthetic medical images that are very difficult to detect and threaten the integrity of scientific publications.¹⁷ Fabrication of text in scientific literature is easier to detect, despite often passing peer review processes. *Tortured phrase* is a term used to describe AI generated text modified

to avoid plagiarism detection software.¹⁸ Tortured phrases are a little like the traditional student using a thesaurus to substitute individual words for better sounding words. Unfortunately, without context, overall meaning could be lost in a synonym or when combined into a phrase, can highlight fabricated text. Katsnelson¹⁸ offers some common examples including the torturing of “big data” to become “colossal information” and “signal to noise” to “flag to commotion.” Perhaps the best way to understand why ChatGPT avoids tortured phrases typical of other AI language programs is to ask ChatGPT.

ChatGPT, like other modern language models, is trained on a massive amount of text data from the internet, which includes both well-written and poorly written text. However, the difference between ChatGPT and older AI language programs is the architecture and training method used.

ChatGPT is built on the transformer architecture, which is designed to learn long-term dependencies in text data. It uses a technique called self-attention to identify relationships between words in a sentence, which allows it to understand the context and meaning of a phrase more accurately.

Additionally, ChatGPT was trained using a method called unsupervised learning, which involves training the model to predict the next word in a sequence based on the words that came before it. This allows the model to learn the underlying structure and patterns of language without being explicitly taught grammar rules or sentence structure.

Furthermore, ChatGPT was trained on a diverse range of texts, which means it has exposure to various writing styles, tones, and voices. This exposure helps the model to understand the nuances of language and produce more natural-sounding responses.

Overall, the transformer architecture, self-attention mechanism, unsupervised learning method, and diverse training data all contribute to ChatGPT's ability to avoid tortured phrases typical of other AI language programs. However, it is not perfect and may still produce awkward or incorrect responses, especially when presented with unusual or ambiguous inputs.

An alarming trend started to emerge where ChatGPT was being listed as a coauthor of journal articles (eg,^{19–21}). In a rapid response, a number of journals have implemented policies against ChatGPT authorship on the basis of plagiarism, inaccuracies, misinformation, and incorrect information²² which has resulted in preprint articles subsequently removing ChatGPT as an author (eg,²³). At the same time, other journals encourage ChatGPT use to help enhance writing style, especially where English is a second language.²⁴ The stable of *Science* journals prohibits use of any text or graphics generated by AI while *JAMA* discourages its use. *Nature* firmly prohibits authorship by large language models on the basis of not satisfying established authorship criteria. The stable of *Wiley* and *Elsevier* journals require transparency of AI generated content, accountability for its accuracy and omission of authorship. Indeed, the standard authorship criteria (*International Committee of Medical Journal Editors*) should prevent authorship by ChatGPT in medical articles independently of a specific policy.

The popularity of ChatGPT has seen an explosion of pseudo-scientific publications in Medline that are informative but more journalistic than scientific writing (eg,^{25,26}), editorials (eg,^{27–32}), letters to the editor (eg,^{33–35}), conversations with ChatGPT (eg,^{36–40}), and even preprint articles prior to

peer review (eg,⁴¹). Indeed, A systematic review of ChatGPT articles, at the time of writing, found 60 relevant journal articles of which only four were classified as research articles (20 were preprint and the remaining 39 were news articles, editorials, letters to the editor, opinions, commentaries etc.).¹² These observations are consistent with an earlier review of ChatGPT in healthcare and research.⁴² While these offer interesting and informative insights into ChatGPT, it is important to look objectively at its actual capabilities.

ChatGPT

What is ChatGPT?

ChatGPT is a large language model developed by OpenAI, a leading artificial intelligence (AI) research laboratory. As a language model, ChatGPT is trained on a vast corpus of text data, such as books, articles, and websites, using a technique called unsupervised learning. The "GPT" in ChatGPT stands for "Generative Pretrained Transformer," which refers to the architecture of the model. GPT models are designed to generate human-like language by predicting the next word in a sequence of text based on the previous words. This allows the model to learn the patterns and structures of natural language and generate coherent sentences and paragraphs. ChatGPT can be used for a variety of natural language processing tasks, such as language translation, text summarisation, and question-answering. One of the most popular applications of ChatGPT is in conversational AI, where it is used to generate responses to user inputs in a chatbot or virtual assistant. ChatGPT is a powerful tool for processing and generating natural language text, with a wide range of potential applications in both industry and academia.

How can ChatGPT help health professionals learn?

ChatGPT can be a valuable tool for health professionals to learn and expand their knowledge on a variety of health-related topics. Here are some ways in which ChatGPT can be helpful:

- Providing quick answers to questions: Health professionals can use ChatGPT to quickly get answers to questions they may have about a particular medical condition, treatment, or procedure. ChatGPT can provide answers based on its vast knowledge base, which can help health professionals learn more about a topic quickly and efficiently.
- Recommending relevant resources: ChatGPT can suggest relevant articles, research studies, or other resources that health professionals can use to learn more about a particular topic. This can help health professionals stay up-to-date on the latest research and best practices in their field.
- Assisting with diagnosis and treatment: ChatGPT can assist health professionals in making diagnoses or

developing treatment plans by suggesting possible causes of symptoms or recommending appropriate treatment options based on patient information.

- Providing language translation: ChatGPT can help health professionals communicate with patients who speak different languages by providing translations of medical terms and phrases.
- Offering personalized learning experiences: ChatGPT can be trained on specific topics or customized to the needs of individual health professionals, providing personalized learning experiences that can help them expand their knowledge and skills in areas that are most relevant to their work.
- Providing case studies and scenarios: ChatGPT can provide case studies and scenarios that health professionals can use to practice their diagnostic and problem-solving skills. These scenarios can help health professionals develop critical thinking and decision-making abilities.
- Supporting continuing education: ChatGPT can assist health professionals in meeting their continuing education requirements by providing access to relevant courses and training materials. This can help health professionals stay up-to-date on the latest developments in their field and maintain their professional certifications.
- Facilitating knowledge sharing: ChatGPT can help facilitate knowledge sharing among health professionals by providing a platform for discussion and collaboration. Health professionals can share their own experiences and insights, ask questions, and learn from their colleagues through the use of ChatGPT.
- Providing patient education: ChatGPT can help health professionals educate their patients by providing information on medical conditions, treatment options, and other related topics in a language that is easy for patients to understand. This can help improve patient outcomes by empowering patients to take an active role in their own health care.
- Generating personalized recommendations: ChatGPT can use patient information to generate personalized recommendations for treatment plans, medications, and lifestyle modifications. This can help health professionals tailor their care to the specific needs of individual patients and improve patient outcomes.
- Providing feedback and assessments: ChatGPT can provide feedback and assessments to health professionals on their diagnostic and treatment decisions, helping them to identify areas where they may need further training or support. This can help health professionals improve their skills and knowledge over time.
- Analyzing medical images and data: ChatGPT can analyze medical images and data to help health professionals make more accurate diagnoses and treatment decisions. This can be particularly helpful in fields such as radiology, where large amounts of data must be analyzed to make a diagnosis.
- Predicting health outcomes: ChatGPT can use patient data and machine learning algorithms to predict health outcomes and identify patients who may be at risk for certain conditions. This can help health professionals to take a proactive approach to care and intervene early to prevent the onset of disease.
- Supporting mental health: ChatGPT can provide resources and support to health professionals who may be struggling with mental health issues such as burn-out, anxiety, or depression. This can help health professionals to maintain their own mental health and well-being, which is essential for providing high-quality care to their patients.

It is important to note that while ChatGPT can be a valuable tool for learning, it should not be relied upon as a substitute for formal medical training or professional advice. Health professionals should always use their own clinical judgment and consult with colleagues and experts in the field when making important medical decisions.

How can ChatGPT be used in radiology and nuclear medicine departments?

ChatGPT can be used in radiology and nuclear medicine departments in a variety of ways. Here are some examples:

- Image analysis: ChatGPT can analyze medical images and data to help radiologists and nuclear medicine specialists make more accurate diagnoses and treatment decisions. This can help identify subtle patterns and abnormalities that might be difficult for humans to detect.
- Predictive analytics: ChatGPT can use machine learning algorithms to predict patient outcomes based on medical images and other data. For example, it can help identify patients who may be at risk for developing certain diseases or conditions based on patterns in their medical images.
- Workflow optimization: ChatGPT can help optimize workflows in radiology and nuclear medicine departments by automating routine tasks and providing real-time insights into patient data. This can help reduce wait times and improve the overall efficiency of these departments.
- Quality control: ChatGPT can assist with quality control by monitoring and flagging inconsistencies or errors in medical images and data. This can help ensure that all patient data is accurate and up-to-date.
- Training and education: ChatGPT can be used to provide training and education to radiology and nuclear medicine students and trainees. It can provide access to a wide range of learning materials and assist with hands-on training.
- Decision support: ChatGPT can provide decision support to radiologists and nuclear medicine specialists by

recommending the most appropriate imaging techniques or treatment options based on patient data. This can help ensure that patients receive the most effective care possible.

- Image annotation and labeling: ChatGPT can be used to annotate and label medical images to improve their accuracy and usability. This can be particularly helpful in fields such as radiation oncology, where accurate image labeling is critical for treatment planning.
- Automated reporting: ChatGPT can help automate the reporting process by generating summaries and reports based on medical images and data. This can help save time and reduce the risk of errors or omissions.
- Virtual consultations: ChatGPT can facilitate virtual consultations between radiologists and other healthcare professionals, allowing for real-time collaboration and decision-making. This can be especially useful in remote or underserved areas where access to specialized healthcare may be limited.
- Quality assurance: ChatGPT can assist with quality assurance by providing real-time feedback on the accuracy and consistency of medical image interpretation. This can help identify areas where additional training or support may be needed.
- Clinical research: ChatGPT can be used in clinical research studies to analyze large amounts of medical image and patient data. This can help identify trends and patterns that may not be immediately apparent to human researchers.
- Patient education: ChatGPT can provide patient education materials to help patients better understand their medical images and treatment options. This can help improve patient satisfaction and compliance with treatment plans.

Overall, ChatGPT has the potential to revolutionize the way radiology and nuclear medicine departments operate, by providing real-time insights, automating routine tasks, and assisting with decision-making. By leveraging the vast knowledge base and capabilities of ChatGPT, radiology and nuclear medicine specialists can improve patient outcomes and provide better care to their patients.

How does ChatGPT threaten academic integrity?

ChatGPT, like any other technology, can potentially threaten academic integrity if used inappropriately. Here are some examples of how ChatGPT could be misused to compromise academic integrity:

- Plagiarism: ChatGPT can be used to generate essays, research papers, and other written assignments. If students use ChatGPT to generate their assignments without proper attribution, they could be committing plagiarism.
- Cheating: ChatGPT could be used to cheat on exams by providing answers to questions in real-time. This could compromise the fairness of exams and lead to inaccurate assessments of students' knowledge and skills.
- Fabrication: ChatGPT can be used to generate fake data or research findings. This could compromise the integrity of academic research and lead to false conclusions.
- Unfair advantage: If some students have access to ChatGPT while others do not, it could give those students an unfair advantage. This could lead to unequal learning opportunities and outcomes.

To mitigate these risks, it is important to use ChatGPT responsibly and ethically. This includes ensuring that students receive proper instruction on how to use ChatGPT as a learning tool, rather than a means of cheating or plagiarism. Additionally, instructors can use plagiarism detection software to identify instances of academic dishonesty and take appropriate disciplinary action. Ultimately, the responsible use of ChatGPT can help to enhance academic integrity rather than threaten it.

How can researchers use ChatGPT in scientific writing?

ChatGPT can be a useful tool for researchers and scientific writing in medicine in a variety of ways. Here are some examples:

- Literature review: ChatGPT can help researchers conduct comprehensive literature reviews by scanning and summarizing thousands of articles, abstracts, and publications in a matter of seconds. This can save researchers significant time and effort, allowing them to focus on more pressing research tasks.
- Data analysis: ChatGPT can assist researchers with data analysis by providing insights and predictions based on large datasets. This can help identify patterns and trends that may be difficult for humans to detect.
- Writing assistance: ChatGPT can help researchers with scientific writing by generating outlines, summaries, and even full paragraphs based on keywords or topics. It can also provide suggestions for improving the clarity and readability of scientific manuscripts.
- Translation: ChatGPT can help translate scientific manuscripts or research papers into different languages, making research accessible to a wider audience.
- Citation management: ChatGPT can assist with citation management by generating bibliographies and citation lists based on specific citation styles.
- Collaborative writing: ChatGPT can facilitate collaborative writing among research teams, allowing members to work together in real-time and share notes and comments.

- Peer review: ChatGPT can help with peer review by scanning manuscripts for errors, inconsistencies, or bias, and providing feedback on the clarity and scientific validity of the research.
- Knowledge discovery: ChatGPT can help researchers discover new knowledge by generating hypotheses based on data analysis and suggesting new avenues of research based on patterns and trends in the data.
- Ethics review: ChatGPT can assist with ethics review by identifying potential ethical concerns in research proposals or manuscripts, such as issues related to informed consent or privacy.
- Grant proposal writing: ChatGPT can help researchers with writing grant proposals by generating outlines, summaries, and even full proposals based on keywords or topics. It can also provide suggestions for improving the clarity and coherence of the proposal.
- Knowledge dissemination: ChatGPT can help researchers disseminate their findings to a wider audience by generating lay summaries or creating multimedia presentations based on their research.
- Peer networking: ChatGPT can facilitate peer networking among researchers, allowing them to connect with other researchers in their field and share knowledge and expertise.
- Teaching and training: ChatGPT can be used in medical education to provide automated feedback on student assignments or to generate customized learning materials based on individual student needs.
- Clinical decision support: ChatGPT can assist healthcare professionals with clinical decision-making by providing real-time insights and recommendations based on patient data and medical literature.

Overall, ChatGPT has the potential to revolutionize the way researchers approach scientific writing and data analysis in medicine. By providing real-time insights, automating routine tasks, and facilitating collaboration, ChatGPT can help researchers work more efficiently and effectively, ultimately leading to better scientific discoveries and improved patient outcomes.

What are some examples of misuse of ChatGPT in scientific writing?

There are several ways in which ChatGPT can be misused in scientific writing. Here are a few examples:

- Plagiarism: ChatGPT can generate text based on a given topic or keyword, which may be tempting for some researchers to copy and paste into their own work without proper attribution. This can lead to accusations of plagiarism, which is a serious ethical violation in scientific writing.
- Misrepresentation of results: ChatGPT may generate predictions or conclusions based on incomplete or inaccurate data, which can lead to misrepresentations

of research findings. Researchers need to be careful when using ChatGPT-generated text to ensure that it accurately represents their research.

- Over-reliance on automation: ChatGPT is a powerful tool, but it should not replace human intelligence and critical thinking. Researchers should avoid relying too heavily on ChatGPT-generated text and should always verify its accuracy and relevance to their research.
- Lack of understanding of technical terms: ChatGPT may generate text that includes technical terms or jargon that researchers may not fully understand. Researchers should be careful to ensure that they understand the meaning and context of any technical terms generated by ChatGPT before using them in their work.
- Misinterpretation of data: ChatGPT-generated text may include predictions or conclusions that are not supported by the available data. Researchers need to be careful to ensure that they are interpreting their data correctly and not making unwarranted assumptions based on ChatGPT-generated text.
- Lack of originality: If researchers rely too heavily on ChatGPT-generated text, they may not be contributing enough of their own original ideas and insights to their work. This can result in a lack of creativity and originality, which is important in scientific writing.
- Lack of accountability: ChatGPT-generated text may be viewed as less accountable than text written by human authors. Researchers should ensure that they take full responsibility for the text generated by ChatGPT and clearly indicate where it was used in their work.
- Lack of transparency: Researchers should be transparent about their use of ChatGPT and clearly indicate where ChatGPT-generated text was used in their work. This can help to avoid any accusations of plagiarism or misrepresentation.
- Biases and inaccuracies: ChatGPT may reflect biases or inaccuracies in the data it was trained on. Researchers should be aware of this potential limitation and take steps to ensure that the text generated by ChatGPT is accurate and unbiased.
- Misuse of authorship: Researchers should avoid listing ChatGPT as a coauthor on their publications. ChatGPT is a tool and should not be considered as a contributing author in scientific writing.

In summary, while ChatGPT can be a powerful tool for scientific writing, researchers must be cautious and responsible in their use of it. They should ensure that they understand the limitations and potential pitfalls of using ChatGPT and always verify the accuracy and relevance of any text generated by it.

Evaluating ChatGPT

The entire “ChatGPT” section above was written by ChatGPT (GPT-3.5). The headings (underlined) were used as the

prompt questions and the answers are transcribed verbatim from ChatGPT. It is easy to appreciate how ChatGPT could be used to assist for simple concepts where information is not ambiguous. It is harder to appreciate value in narrow or specific topics where there is a requirement for deeper insights or consideration of context. For example, ChatGPT was asked how the OPAL reactor works (ANSTO research reactor in Australia), and provided a commentary of useful facts available publicly, omitted key information that is difficult to find or absent from public databases, and added an extrapolation of common information but interpreted out of context (bold text below) to produce false or misleading information.

The OPAL (Open Pool Australian Lightwater) reactor is a research reactor located in Lucas Heights, a suburb of Sydney, Australia. It is operated by the Australian Nuclear Science and Technology Organisation (ANSTO) and is used for a variety of purposes, including the production of medical isotopes, scientific research, and industrial applications.

The OPAL reactor is a low-power, multipurpose reactor that uses low-enriched uranium (LEU) fuel. **It operates using a pressurised light water coolant system, which circulates water through the reactor core to transfer heat generated by nuclear fission to the steam generators. The steam produced is used to generate electricity, which is then used to power the reactor and other facilities at the site.**

One of the unique features of the OPAL reactor is its open pool design, which allows for easy access to the reactor core for research and maintenance purposes. The reactor core is surrounded by a large pool of water, which acts as a radiation shield and helps to cool the fuel elements. The OPAL reactor also has a number of safety systems in place to ensure that it can be shut down quickly and safely in the event of an emergency. These include backup power supplies, emergency cooling systems, and redundant control systems.

Overall, the OPAL reactor is an important facility for research and development in Australia, and plays a critical role in the production of medical isotopes used for cancer diagnosis and treatment.

Undergraduate nuclear medicine and radiography subjects had examinations and written tasks performed using ChatGPT and then marked against standard rubrics. ChatGPT performance was compared to student cohort means.⁴³ For written tasks, ChatGPT performed poorer than the average student and the disparity between student and ChatGPT increased as the tasks expectations increased (first through to third year). ChatGPT similarly had worsening performance with higher expectations in examinations but performed better than the student average for subjects with learning outcomes of a general nature (compared to deeper insights of profession specific subjects). Turnitin AI prediction software readily identified AI generated text excepting an advanced nuclear medicine subject. The authors concluded that ChatGPT has limited capacity to assist nuclear medicine and radiography student writing due to the risk of misconduct (plagiarism and information fabrication), and because answers lack depth of insight, breadth of research and currency of information.⁴³ These same limitations restrict usefulness as a content generator for learning. A potential role identified was for quality assurance of examination papers to find errors and correct ambiguous wording.

Among eight nuclear medicine specific undergraduate subjects in second and third year of studies, ChatGPT performed poorly in calculation exams (mean of 31.7% compared to 67.3% for students), failed each written task (mean of 38.9% compared to 67.2% for students), performed better than students for general or early subjects but performed poorly in advanced and specific subjects (mean 51% compared to 57.4% for students).⁴⁴ The authors concluded that ChatGPT is constrained by higher order taxonomies, also limiting usefulness for enhancing learning. A potential role identified was for using ChatGPT to generate information for students to subsequently critique and edit as a learning or assessment task.

Multiple choice questions for preparation for step 1 and step 2 of the US Medical Licensing Examination were also evaluated with ChatGPT.⁴⁵ Among four data sets, step 1 had 44% and 42% results while step 2 had 64.4% and 57.8% but ChatGPT performance was considered equivalent to a passing grade third year medical student.⁴⁵ Other investigators have also used ChatGPT with the US Medical Licensing Examination²³ for step 1, step 2, and step 3 and reported ChatGPT to perform “near passing level.” Similarly, ChatGPT did not meet the passing requirements for the American Heart Association Basic Life Support or the Advanced Cardiovascular Life Support examinations, despite the advantage of having questions with images or electrocardiogram interpretation removed.³³ In Korea, ChatGPT performed poorly against medical students in a parasitology exam with ChatGPT scoring 30% lower than students although student scores were suspected to be higher due to the proximity of the exam to learning the material.⁴⁶ In nuclear medicine specialist examinations, ChatGPT was only able to score 34% among 50 multiple choice questions with a 24% score being attributable to random guessing.⁴⁷ Of greater concern was ChatGPTs propensity for confabulation when questions with incorrect answers were asked a second time. As outlined by Alberts et al.⁴⁷, a nuclear medicine physician needs to practice within their capabilities and recognizing when information is not known is far more important than crafting a convincing but inaccurate response. These observations are more consistent with the confounding of ChatGPT by nuclear medicine specific questions in technical exams.⁴⁴

ChatGPT was also used to generate patient information sheets aimed at gaining informed consent.⁴⁸ Among 11 common procedures, ChatGPT was critiqued to have an appropriate tone for patient communication but the actual content was inaccurate and omitted key information. The errors and misleading information were considered detrimental to patient education and professionalism.⁴⁸ ChatGPT generated cancer information was evaluated against the US National Cancer Institute’s common cancer myths and misconceptions questions and answers. Accuracy with blind evaluation was 100% for the National Cancer Institute’s answers and 96.9% for ChatGPT with no difference in text readability identified.⁴⁹ While this suggests suitability of ChatGPT for generating patient information, the questions were very general in nature and had been directly answered online, information likely to have been included in GPT-3.5 training. A

key issue is that ChatGPT tends to over-answer simple questions, producing additional information that could cause unnecessary concern.

The limitations of ChatGPT were evaluated and exposed using a 2022 journal article (not in ChatGPT's learning database) and basic facts extracted from the article.⁵⁰ ChatGPT was prompted using open-ended questions to summarize key facts using regenerated answers five times. The ChatGPT quintuplicate responses included falsified and fabricated information, and inaccurate and misleading information.⁵⁰ This highlights the significant variability in ChatGPT performance from shallow and general information that is historically stable⁴⁹ to complex information requiring deep insight and context⁴⁸ to specific information outside the training set.⁵⁰ ChatGPT was also prompted with simulation data to craft a research article.⁵¹ While the authors were happy ("excellent job") with the description of data and statistical approaches suggested by ChatGPT, they were far too shallow and lacked the specifics of statistical tools to be accepted through journal peer review or for a research proposal (eg, grant application). Circumventing the plethora of statistical analysis tools readily available, ChatGPT was used to write specific code for data analysis and highlighted coding capabilities and the need for human error detection.⁵¹ Only after the data were analysed was ChatGPT asked to generate an abstract for the paper (often the last part of actual scientific writing) and then to generate a literature review (presumably something that should be undertaken before the research started) including a number of fabricated citations. While the limitations were recognized by the authors, for an experienced researcher one might expect conventional scientific writing to be more accurate and efficient than the sometime arduous prodding and subsequent fact checking of ChatGPT. Nonetheless, ChatGPT, if asked, provides convincing and detailed insights into its capability in supporting the production of a scientific manuscript in radiology.⁴⁰

An interesting set of applications of ChatGPT relate to patient histories. ChatGPT has been used to produce detailed discharge summaries.²⁷ In the emergency department, ChatGPT has been used to evaluate patient history and symptoms to triage urgent patients.³⁴ By extension, used in conjunction with the triage nurse, ChatGPT could improve the accuracy of overall triaging in emergency care.³⁴ Like other AI algorithms, the risk of bias in triaging due to lack of diversity in the training set could create inequity and the legal and ethical issues of AI augmented triaging are yet to be challenged. In nuclear medicine and radiology, this triaging capability could be adapted to identify patients requiring priority reporting and this could be especially useful with GPT-4 where images can be used as an input. ChatGPT has also been used in radiology to identify the most appropriate imaging procedure.⁴¹ The results revealed ChatGPT to be able to accurately guide imaging for patients presenting for breast cancer screening (89% score) but was less suitable for breast pain guidance (58%). Despite variable results, ChatGPT could be used in nuclear medicine and radiology to improve clinical workflow by augmenting decision-making.

Discussion

For nuclear medicine, and perhaps radiology, the future impact of ChatGPT is hard to predict. One might reasonably expect future iterations of ChatGPT to further enhance capability and address existing limitations. Alberts et al.⁴⁷ postulate that ChatGPT will soon be able to produce a research paper without prompting and wonder whether nuclear medicine conferences might soon be inundated by AI-generated abstracts. The scourge of scientific writing is the predatory journal, and the possibility that ChatGPT might be able to feed such journals with fraudulent or flawed manuscripts could spawn a larger volume of low-quality articles.⁴⁷ Could fuelling the fire burn it out? A potential issue for the literature is the capability of ChatGPT to, on mass, produce letters to the editor for a raft of articles.

ChatGPT was provided the abstract for a recent article on digital twins¹⁵ and asked to write a letter to the journal editor about the whole article making sure to raise a concern.

Dear Journal Editor,

I am writing to share my thoughts on the recent article on the potential of artificial intelligence (AI) in radiation dosimetry and precision medicine. The article highlights how AI, particularly convolutional neural networks and deep learning, has the potential to solve problems that have previously confounded human intelligence. Specifically, accurate prediction of radiation dosimetry pretreatment with scope to adjust dosing for optimal target and nontarget tissue doses is consistent with striving for improved outcomes of precision medicine.

The authors propose that the combination of AI and the production of digital twins could provide an avenue for individualized therapy doses and enhanced outcomes in theranostics. This is an exciting and promising prospect, given that personalized medicine has the potential to greatly improve patient outcomes. However, as the authors note, there are certainly barriers to overcome, including the need for large amounts of high-quality data, as well as regulatory and ethical considerations.

One concern I have is the potential for AI to perpetuate or exacerbate existing biases in medical decision-making. If the data used to train AI algorithms are biased, then the resulting predictions and decisions will also be biased, which could lead to inequitable outcomes for certain patient populations. It is important that researchers and practitioners in this field are vigilant about detecting and addressing bias in AI-based medical decision-making.

Nevertheless, the maturity of individual technologies such as radiation dosimetry, AI, theranostics, and digital twins places these approaches within reach. The article provides a comprehensive overview of the current state of the field, including recent advances in AI-based radiation dosimetry and the use of digital twins in the context of precision medicine. The authors also discuss potential future directions and challenges in this field, which will undoubtedly be of great interest to researchers and practitioners alike.

Overall, I found this article to be a valuable contribution to the field of precision medicine and the role of AI in radiation dosimetry. I hope that this work will inspire further research and development in this area, while also raising awareness of the importance of addressing bias in AI-based medical decision-making.

Thank you for considering my thoughts.

Sincerely,

Context is important. The intended use for ChatGPT and the actual use creates a gap in expectations. Much of the initial hype falls beyond the intended use of ChatGPT and this

will perhaps normalise. While ChatGPT can produce simple text or code, errors are common. Incorrect information from ChatGPT (confabulation) can create liability issues related to medical advice.³² An important distinction is that ChatGPT is designed to create readable text not to create medically accurate predictions typically associated with medical AI.³² Medical misinformation in the information age is not a new challenge (eg, “Dr Google”). The value of ChatGPT will rely on how errors are identified and managed. If errors are overlooked, ChatGPT generated information becomes misinformation. For example, ChatGPT generated scientific abstracts being passed through review processes and published.⁵² For student learning, ChatGPT errors are likely to reinforce misinformation and be counter-intuitive to learning enhancement because students using it are less likely to identify the errors. Conversely, using ChatGPT generated text as a tool for students to critique and edit could enhance both writing skills and knowledge. Those leaning on ChatGPT for writing assistance need to carefully fact check every sentence which may not be consistent with the motivation for using ChatGPT in the first place (eg, time pressure).

ChatGPT could be used to consolidate a vast amount of new information (monthly journal articles in medicine) for more ready digestion.³² The potential for error, misinterpretation, and incorrect prioritization of information in such a process is likely to leave a sour taste in the mouths of those with an appetite for the medical literature. A number of potential applications for ChatGPT in nuclear medicine and radiology include:

- Normalization of language between multiple medical disciplines so that the same expressions are used for the same observations (eg, between radiology CT reporting and nuclear medicine PET reporting, or cardiologist vs physician for cardiac studies).³²
- Normalization of medical language to be more interpretable for patients and their carers. Terminology and phraseology can make sense to the health professional but be nonsensical or confusing with decreasing health literacy.³⁷
- Producing a consolidation of large volumes of information (eg, medical histories or conference proceedings) into a usable summary.
- Triage patients for priority reporting and identifying appropriate procedures based on patient history and symptoms.
- Translation of information (eg, patient information or scientific reports) between languages.

While there is a general view that ChatGPT could be used, in part at least, to help scientific writing for students or for health professionals,⁵³ considerable proofreading and fact checking is required, citations need to be thoroughly checked for authenticity, and there remain concerns associated with social asymmetry. That is, inequitable accessibility to ChatGPT based on socioeconomic factors.⁵³

ChatGPT has acceptable accuracy for some general topics but is prone to a number of different type of errors. The term

hallucination has been used widely to refer to false or misleading information produced by AI.⁵⁴ A *hallucination* is a plausible response that is incorrect (it seems correct to ChatGPT but is not).⁵⁴ For example, explaining a non-existent alpha therapy radionuclide or identifying a clinical application of nuclear medicine that does not exist. The term *delusion* is also used for a false belief or error (wrong information).⁵⁵ For example, explaining nonionising radiation like MRI and ultrasound are both electromagnetic radiation. A *confabulation* (or a lie) is fabrication of information due to a memory error.³² For example, generating fake citations, images or data to support a thesis or report. Extending the psychiatric analogy of hallucination, since it does not adequately define other errors typical of ChatGPT, an *illusion* is like a hallucination except it is an error of similarity (mixing up similar items). For example, explaining targeted radionuclide therapy as brachytherapy. *Delirium* is either a sophisticated or nonsensical answer caused by the algorithm being overwhelmed or confused, particularly if the query is ambiguous or requires pragmatics. For example, explaining how therapy works when asked about diagnosis. In addition, ChatGPT is prone to errors of *extrapolation* or interpolation where generated text is a logical extension of known information, although incorrect. For example, explaining that the OPAL research reactor produces electricity by steam turbine for local electricity needs. A *miscalculation* relates to computational errors, often despite the correct equation and data. For example, correctly identify the radioactive decay equation, coding the correct values in the equation but computing the incorrect answer. Interestingly, ChatGPT may appear to have changes in mood, in responses to questions. For example, in a single session of interaction, ChatGPT elaborately fabricated a response to a question referring to an image not available to ChatGPT (incorrectly) and then in identical circumstances responds with a request for more information on the basis that it does not have access to the image. Writing style and tone can also switch mid-session. For example, when asked to provide the correct response to a multiple choice question, ChatGPT typically states the answer followed by a justification but may undergo a mood change mid-session and start responding with a short sharp answer alone or switch to a more casual narrative style discussion concluding with the answer identification.

The purported benefits of ChatGPT in the health sector⁸ are somewhat a double-edged sword.²² Rapid assistance and resource accessibility loses its value when substantial time is required to fact check, given the vulnerability ChatGPT has to errors. Writing assistance is beneficial, particularly where English is a second language, but ChatGPT lacks the range for writing professional standard text. Research support is substantially limited because ChatGPT has repeatedly been shown to fabricate sources and information, and lacks the depth of insight and breadth of understanding to be useful beyond superficial and narrow tasks. Preparation of learning material and examination preparation is shackled by ChatGPTs lack of deep insight into complex information, potentially harming human learning and understanding with misinformation. Summary assistance could be efficient but if

ChatGPT does not understand deeply the content, decision making on which content to include and which to reject could bias the summary information produced. Generation of clinical documentation has been shown to be particularly risky given misinformation generated for patients can have significant negative consequences. In a rapidly evolving industry, like nuclear medicine and radiology, currency of information compounds lack of accuracy.

An interesting point of discussion is the use of ChatGPT to help with research, specifically simplifying the literature search process.⁵⁶ As described,⁵⁶ ChatGPT makes a literature search less arduous, comparing ChatGPT to an extremely knowledgeable professor able to use their vast experience and insights to provide research shortcuts. The issue is that neither approach is acceptable in research and evidence-based practice because of bias, omission, lack of currency and error. The arduous nature of a systematic review of the literature is useful in minimising bias and improving the validity of any subsequent work. Indeed, to operate at an appropriate standard, starting with ChatGPT would make the overall task more arduous with the current version of GPT-3.5 driven ChatGPT. Reliance on ChatGPT as a research assistant could see the scientific method devolve and risk integrity of future research outcomes.

The generative AI and large language models space is, however, rapidly evolving. The new edition (GPT-4) is orders of magnitude superior to GPT-3.5 and adapts to context and to complexity. At the time of writing GPT-4 was only available in ChatGPT through paid subscription although it is used to power Bing Chat (Microsoft). For ChatGPT powered by GPT-4, problem solving will improve and it can learn to write in the style of the user. Images can be entered into GPT-4 and this may create opportunities for image analysis, broadening the scope of ChatGPT capability and making use more flexible.^{57,58} Performance in responses has also improved in accuracy by 60%.^{57,58} GPT-4 is trained on 45 GB of data compared to just 17 GB for the current version. ChatGPT uses an identifiable phraseology due to limitation of 175 billion parameters (GPT-3) and this could be detected by plagiarism software. GPT-4 has 100 trillion parameters and a 500-fold increase in capacity, which produces more adaptable and versatile language generation with text that is more accurate and original, and more challenging for AI detection software. ChatGPT powered by GPT-4 can also develop or edit code and produce outputs up to 52 pages (compared to the previous three-page maximum). Up to 25,000 words can be inputted by users to assist with editing and refinement of written work. Evaluations of capabilities and limitations of ChatGPT will need to be repeated when GPT-4 is publicly available.

Albert Einstein was attributed as saying that “information is not knowledge” but the origin of the thought came from an 1879 Fletcher Prize Essay⁵⁹, p. 59. Knowledge can be shared or communicated by primary or expert sources. ChatGPT is a secondary source that lacks the expertise and context to do anything more than simply share information (or mis-information); “the blind leading the blind.” The Alexander Pope maxim “a little bit of knowledge is a dangerous

thing”⁶⁰, p. 18 parallels the dangers of ChatGPT in the health and medical domain, whether student, practitioner or patient, producing a false knowledge economy and the false confidence in capability that accompanies it; the Dunning-Kruger effect.⁶¹

Conclusion

The emergence of AI has challenged the traditional approaches to learning and clinical practice. A quantum shift occurred in higher education and in clinical practice in the post COVID era.^{62,63} Consequently, nuclear medicine practice is not so wedded to the boundaries and conventions of the current environment that we cannot pivot to accommodate the emergence of ChatGPT. Large language models like ChatGPT can, however, be misused to produce scientifically convincing text with inaccurate or misleading information. ChatGPT in academic and scientific writing is certainly not hype although its flaws and limitations leave it well short of ideal or iconic (hero). At the same time, ChatGPT need not be automatically cast as heresy; appropriate management of misuse potential could unveil a helpful education and writing companion as a “weapon of mass construction.”

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.

Acknowledgment

I would like to acknowledge the contribution of ChatGPT (version 3.5), a language model developed by OpenAI (<https://openai.com/>), in generating some of the text in this manuscript. The model was accessed between March 14 and April 20, 2023.

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