A ChatGPT Assisted Reading Protocol for Undergraduate Research Students Engaging with Biophysics Literature

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Abstract

A major challenge for undergraduate students engaged in research is reading scientific literature. This is especially true for students engaged in biophysics research, where many of the concepts, definitions, and experimental methodologies discussed may be beyond the material covered in standard undergraduate courses. Without specific guidance on how to read journal articles, students can become overwhelmed, which may lead to students reading fewer papers and not engaging with the scientific literature related to their research. To help undergraduate students effectively engage with scientific papers, we have developed a guided reading protocol that combines pre-reading strategies, structured notetaking, and the use of ChatGPT. Using ChatGPT in this protocol allows students to clarify unfamiliar terms and concepts in an interactive way that helps them to integrate the paper's content into their own understanding. To test the impact of this protocol, participants in this study were given an initial survey to determine their comfort and experience with reading scientific literature. After this they were given an abridged biophysics paper and the ChatGPT assisted guided reading protocol. The ChatGPT transcripts were analyzed using open coding and the students were given a post-study survey to determine how they felt about their experience using ChatGPT. We found that most students do not appear to engage with the literature regularly, which may be due to barriers they encounter in terms of new and unknown content. Analyzing their conversations with the chatbot, we observed that students asked for definitions, explanations of unknown concepts, summaries of text or their own

understanding, and simplifications of the text. Overall, students reported in the post-implementation survey that using ChatGPT was a positive experience and all students reported that they expected to use ChatGPT in the future when reading scientific literature. From this work, we believe that this new chatbot assisted reading protocol may be a way to keep novice biophysics students from becoming discouraged when they begin reading scientific literature and help keep them engaged with the current literature in the field.

Introduction

When an undergraduate joins a research lab they encounter scientific literature, often for the first time, that goes beyond what they have encountered in their coursework. Undergraduates engaged in biophysical research, especially, must grapple with structural biology and biophysics papers with unfamiliar terms, concepts, and methodologies. Encountering these new ideas as well as the complexity and unique format of scientific literature act as barriers, preventing students from engaging with the literature in a meaningful way. Without supports and guidance, reading literature may cause anxiety that can hinder the learning experience for the undergraduate researcher.[1] Gaining competency in reading literature is necessary not only for developing scientific skills but also contributes to improving student motivation and sense of belonging in their field, which is critical for retaining students in the sciences.[2-6]

Although this is an important topic for training students to be scientists, limited studies on how undergraduate STEM students approach reading scientific literature have been reported. A study by Lennox and colleagues indicated that undergraduates use a spectrum of approaches to find evidence in reading primary scientific literature, and while most students were able to identify the main points of a given text, they struggled to provide evidence for their conclusions.[7] A study by Mitra and colleagues observed that many undergraduate STEM students struggled to identify the research hypothesis of articles while participating in a guided literature reading curriculum.[8] Additionally, studies observed a disconnect between students' self-perception of their scientific reading comprehension ability and their actual skills,[7, 8] which may contribute to undergraduate students not fully engaging with literature because they do not realize that they are not doing so effectively. Reading scientific literature requires different skills than "everyday" reading,[6] and these skills need to be explicitly taught to undergraduate research students along with the use of new technologies, such as ChatGPT, to help students fully engage with the material.

Scientific and Pedagogic Background

Interventions have been developed and assessed to help undergraduate STEM students engage with scientific literature more effectively. In a project by Round and colleagues, a template called "figure facts" was used to help students read and interpret scientific literature by having students focus on experimental data presented in an article's figures. Students showed improvement in data interpretation and attitudes about reading scientific literature.[2] Mitra and colleagues developed a curriculum to guide undergraduates' reading of scientific articles by focusing on the hypothesis and conclusions drawn from experimental results using a series of guided worksheets and workshops. They found that students' confidence improved with the curriculum.[8] Gold and colleagues embedded a scientific literature reading and graph

interpretation curriculum into a ten week REU program. They analyzed the reading strategies used via survey and eye-tracking studies to compare REU participants to experts, and found that with the embedded curriculum and authentic research experience in the REU, participants made gains in their reading strategies and graph interpretation skills.[6] To advance undergraduates' scientific literacy and understanding of the publication process, Otto and colleagues developed a curriculum in which students peer reviewed preprints, which was found to improve students' scientific literacy and sense of belonging in STEM.[9]

These interventions have greatly helped students' understanding of the format and reading of scientific literature. However, conventional methods are unable to address the issue of encountering unfamiliar terms within the context of a research article in a timely manner, so as to not frustrate and discourage the student. This is especially important when undergraduates are doing research and reading journal articles in a multidisciplinary field like biophysics, where they need to engage with terms that are outside the scope of the material they have learned in their classes. This study aims to show that a guided reading protocol that includes artificial intelligence (AI) based Large Language Models (LLMs) such as ChatGPT can be used to bridge knowledge gaps and help undergraduate research students effectively read and understand scientific literature.

The advent of LLMs like ChatGPT has quickly changed how individuals interact with information. These new tools can be used for answering questions, summarizing information, and can play a role in improving equity by minimizing language barriers for diverse learners.[10-13] Many interesting use cases for AI in postsecondary science education are already being explored and analyzed in the literature. A common theme in published studies is the importance of training students in AI literacy so that they understand how to use a tool such as ChatGPT effectively and understand its limits.[4, 10, 14-18] Further, much of the literature has highlighted the need to develop training for students in prompt engineering, the process of crafting AI queries to elicit better answers.[13-17] Tassoti developed a structured framework for posing questions to ChatGPT in a way that led to satisfactory responses without needing to copy large sections of text into the chat.[16] While nearly all studies stress the importance of prompt engineering, studies on the use of LLMs in STEM education vary in how the students are interacting with the chatbot. In one study by Exintaris and colleagues, students were introduced to problem-solving methods, taught a metacognitive scaffolding approach for problem solving, and then asked to critique a ChatGPT generated solution to a problem. Most students were able to find flaws in the LLM-generated results, showing that with scaffolding students were able to think critically about the responses provided by ChatGPT.[19] A study by Pence and colleagues involved analyzing a three-part assignment for undergraduate chemistry students: students used ChatGPT to summarize an article from a chemistry trade magazine, analyzed ChatGPT output for a numerical solution, and used ChatGPT to analyze primary scientific literature by using it to answer specific questions. In summarizing the trade magazine article, the students largely felt this was a good use of the LLM, and that the summaries were generally accurate but superficial. For the assignment involving using ChatGPT to answer questions from primary scientific literature, results were mixed. Students became frustrated with prompting, and some hallucinations and superficial answers occurred. However, when analyzed by faculty it was found that the majority of responses from ChatGPT were at least partially correct.[20]

To facilitate effective engagement with scientific literature for undergraduate research students, we have developed a new approach that combines pre-reading strategies adapted from the book, *Teaching Students to Learn* by McGuire[21], notetaking, and the use of artificial intelligence-based Large Language Models (LLMs) like ChatGPT. The LLM assists students in clarifying unfamiliar terms and concepts, preventing these from becoming barriers, thus enabling students to better integrate the paper's content into their own research.

Methods

Research subjects were recruited via an email from the pool of undergraduate students participating in research in the chemistry department at a primarily undergraduate institution. The students ranged from second to fourth year students with less than one year to two years of undergraduate research experience, with majors in chemistry, biochemistry, and biology. A pre-intervention survey was given to assess the students' prior experience and comfort level with reading scientific literature and with using AI chatbots such as ChatGPT.

After completing the initial survey, students were sent two items: a ChatGPT-assisted literature reading protocol and the title, authors, abstract, and introduction of the 2018 paper "Stabilized Coronavirus Spikes are Resistant to Conformational Changes Induced by Receptor Recognition or Proteolysis" by Kirchdoerfer *et al* [22]. This structural biology paper was chosen because we expected it to present unknown terms and methodologies to chemistry or biology research students, but the coronavirus subject matter would still provide some familiarity. The paper was abridged to these sections because the introduction is often read first by students and it is where many unfamiliar terms and concepts that may act as barriers would be presented.

The ChatGPT-assisted literature reading protocol consisted of four elements to guide the students in using the chatbot as a tool for understanding scientific literature. This procedure is also included in the supplemental information as Figure S1.

1. **<u>Previewing the paper</u>.** The reader is encouraged to analyze the title, abstract, headings, and figures to gain meaning.
    a. <u>Analyzing the title</u>. The reader is asked to pick out key words that give the paper's main focus.
    b. <u>Analyzing the abstract</u>. The reader is encouraged to analyze the abstract for (1) key findings and (2) the general format of an abstract: importance, problem to be addressed, approach, and insights.
    c. <u>Analyzing headings and figures</u>. The reader is also asked to skim text headings and figures to anticipate the questions the paper will answer. It should be noted that the abridged paper we provided did not in this case include a figure.
2. **<u>Guided reading of the paper</u>.** In reading the paper, the reader is told to highlight key text with an erasable method and to refine/edit highlighting as they read. The reader is also asked to make margin notes of important points and if needed, extended notes in a separate notebook.
3. **<u>Using ChatGPT for clarifications</u>.** The reader is told to use ChatGPT to help clarify unfamiliar concepts, terms, or methodologies that feel like stumbling blocks, and are walked through how to effectively use ChatGPT for this purpose:

a. Introduce yourself. First, the reader introduces themselves with their academic and research background and any other pertinent information.
b. Introduce the paper. The reader informs ChatGPT about the paper, giving the paper's title and general field.
c. Ask questions. The reader asks questions to ChatGPT and is encouraged to ask clarifying or follow-up questions as needed.

4. **Post-reading summary:** Lastly, the reader is encouraged to review their notes and ChatGPT transcript to write a summary of the paper. The summary can be as brief as one or two sentences or bullet points to synthesize ideas and serve as a record of the paper for the reader.

Students were asked to save their ChatGPT transcripts as PDF files and send them to researchers via email upon completion of the guided reading task. The ChatGPT transcripts were anonymized prior to analysis. Students were then sent a post-implementation survey about their experience using the ChatGPT-assisted literature reading protocol.

Responses to multiple selection and Likert-scale questions on the pre-and post-implementation surveys were tallied, and free response questions were coded using open coding for common themes.[23] ChatGPT transcripts were analyzed in two ways. First, the number of questions asked by each student was tallied. Second, open coding was used to analyze the types of questions being asked to ChatGPT. Five question-type codes emerged. Questions corresponding to these codes were tallied.

Results and Discussion

Pre-implementation survey

In the pre-implementation survey, students were asked about their experience with and perceptions about scientific literature. Fourteen students responded to this survey. The first part of the survey asked about experience reading journal articles, and the second part of the survey asked about approaches to reading journal articles and previous experience using LLMs such as ChatGPT.

Students were asked to rank their confidence in reading scientific literature, with 57% (8 of 14) of respondents saying they felt confident or very confident and 29% (4 of 14) saying they felt moderately confident reading literature. However, this self-reported measure did not correspond with students' actual limited experience reading literature, in agreement with previous studies that undergraduate students often overestimate their reading skills.[7, 8] When asked how many journal articles students read per month related to their research project, 29% (4 of 14) of students reported not reading any journal articles, 64% (9 of 14) reported reading 1-2 articles, and only 7% (1 of 14) reported reading 3-4 articles. Students reported mixed views on how well they felt their research mentors and course instructors prepared them to read scientific literature with 43% (6 of 14) of students agreeing or strongly agreeing that faculty have taught them to read scientific literature. The most common strategy students reported being taught was to read the abstract first and then look at the figures (36%, 4 of 11). While the undergraduate researchers

in this study expressed confidence in their ability to read scientific literature, they also indicated a lack of experience and instruction on how to approach reading journal articles.

When asked about approaches students take to reading scientific literature (allowing for multiple responses), the most common approach was reading the abstract first (64%, 9 of 14) followed by reading the article from beginning to end (50%, 7 of 14) and jumping around the article (50%, 7 of 14). Reading the abstract first was the most common strategy students reported being taught. We also asked students what they do when they encounter an unfamiliar word, phrase, or concept (allowing for multiple responses). The most common response was using a search engine such as Google (93%, 13 of 14), followed by using LLMs such as ChatGPT (50%, 7 of 14). We can see that undergraduate student researchers are using online resources to decode unfamiliar terms and concepts, but generally without specific guidance that would help them do this effectively and efficiently.

In a write-in response question, the students were asked what they perceive to be the most difficult aspect of reading scientific literature. Two common themes emerged: encountering unfamiliar vocabulary, terminology, and abbreviations (46%, 6 of 13) and deciphering scientific writing in terms of its length, density, and style (54%, 7 of 13). Undergraduate students appear to be employing tools such as search engines and LLMs on their own to tackle the challenges of reading scientific literature, but still perceive significant barriers to their understanding. This suggests that training research students to use LLMs such as ChatGPT can be a productive tool for removing the obstacles of unfamiliar terminology. It may also be beneficial for undergraduates who are tackling difficult scientific literature, possibly for the first time.

ChatGPT Transcripts

A total of eleven students completed the ChatGPT-assisted reading of the article and returned the ChatGPT transcripts for analysis. Anonymized ChatGPT transcripts were analyzed for (1) number of interactions initiated by each student and (2) common types of questions and statements that were posed by the students. Here, we counted interactions as either giving background information to ChatGPT or asking a specific question. The average number of interactions with ChatGPT was 7.1 interactions, with a range of 5 to 14 interactions in each transcript.

To investigate how undergraduate research students were interacting with ChatGPT, open coding was used to group the types of questions and statements posed into five common themes.

1. **Background**. The student gave information about their educational background as they were prompted to do in the user guide (82%, 9 of 11 students used this type of interaction).

   In giving background information, students gave information about their educational background, and some gave information about their experience reading scientific journal articles. Students were prompted to provide information about their academic background in the provided reading guide, to allow ChatGPT to tailor its response to the individual's educational level.

All students who gave background information described their educational background in terms of major and relevant courses completed. For example:

"I'm currently a third-year chemistry student in my second semester. I've taken two semesters of general chemistry and organic chemistry, each with analytical chemistry and quantum mechanics classes. I am enrolled in a thermodynamics class right now. I have a very light background in biology, mostly pertaining to protein structures, but chemistry is more of my strong suit."

Of the students who gave background information, 44% (4 of 9) also gave information about their research interests and experience, which was in addition to what they were prompted to do in the reading guide. For example:

"I am a third-year college student majoring in biology. I have taken courses such as general chemistry, organic chemistry, and biology courses such as microbiology and now biochemistry. I also currently do research in a chemistry lab doing analytical chemistry comprised of measuring absorbance using a UV-Vis spectrometer. **.** *I rarely read scientific papers and it takes me a long time to thoroughly comprehend even a few sentences."*

2. **Definition.** The student asked for the definition of an unfamiliar term (100%, 11 of 11 students used this type of interaction). All students asked definition questions pertaining to unfamiliar words and phrases in the text. We saw in the pre-implementation survey that unfamiliar terms are common stumbling blocks in reading scientific literature. Using an LLM to obtain definitions quickly without having to evaluate multiple sources may help undergraduate researchers to persevere in reading scientific literature quickly and help keep them from feeling discouraged when encountering new concepts. Example definition questions included:

   "What does the word "zoonotic" mean?"

   "What is single-particle cryo-EM and what does an ectodomain do?"

3. **Explanation.** The student asked for an explanation about a concept from the text (82%, 9 of 11 students used this type of interaction).

   In these questions, students asked for an explanation rather than just a definition about the text itself. Explanation questions frequently came after a definition question as the subject aimed to further understand a new term or idea within the context of the definition they received. Examples include:

   "Why is it important to prevent the transition from pre-fusion to post-fusion states for the stabilized coronavirus spikes?"

   "Why are coronavirus spike proteins trimeric? Does this contribute something important to their function?"

4. **<u>Summarize</u>.** The student asked for summary of information from the text or summary of ChatGPT response (36%, 4 of 11 students used this type of interaction).

   Summarize-type questions posed by students took two different forms. Most students gave either the digital object identifier (DOI) of the paper or large quotes from the paper and asked for a summary of the text. This may have been done to lower cognitive load for the reader when encountering scientific literature on an unfamiliar subject. An example of this is:

   "The paper I need help understanding is 'Stabilized coronavirus spikes are resistant to conformational changes induced by receptor recognition or proteolysis' (DOI: 10.1038/s41598-018-34171-7). Could you please summarize the abstract?"

   Students also used summarize-type questions to give a summary of their understanding and prompt ChatGPT to respond and add clarification to the summary in order to critique and deepen their own understanding. An example is:

   "I have just completed reading the abstract and introduction of Stabilized coronavirus spikes are resistant to conformational changes induced by receptor recognition or proteolysis, a biochemistry journal article. The intro gives the background behind the experiment and its importance while the abstract summarizes the article in a brief paragraph. The intro discusses coronavirus strands like MERS-CoV and SARS-CoV but focuses on the latter. The virus contains large trimeric S-glycoproteins, which aid in recognizing host receptors and virla [sic] *cell entry. As SARS-CoV breaks down into subunits S1 and S2, with S2 having the S2 cleavage site and S1 with N terminal domains and receptor binding domain. Using cryo-EM analysis, the researchers were able to develop to stop* [sic] *the transition of pre to post fusion states."*

   From this example, after the student shared their summary, ChatGPT provided definitions of many of the terms the student used (such as subunits S1 and S2) without prompting, and the student replied with follow-up definition and explanation questions. This interaction allowed the student to check and organize their understanding of the material and receive details and feedback from ChatGPT.

5. **<u>Simplify</u>.** The student asked ChatGPT to either simplify language from the journal article or simplify its own explanation in terms of language used or length of explanation (46%, 5 of 11 students used this type of interaction).

   Students approached asking for simplifications in different ways. Some primed ChatGPT in their introductions to use simple language in its responses. These students may have recognized that complex language and unfamiliar terms are a barrier for their own understanding of scientific literature before reading the article. For example:

   "I am going to be using your help to analyze and understand a journal article about coronavirus. The article is titled 'Stabilized coronavirus spikes are resistant to

conformational changes induced by receptor recognition or proteolysis.' When you explain things please keep it simple and understandable."

Other students requested simplification as they read different parts of the article to improve understanding of challenging material. For example:

"Could you please simplify the third paragraph in the introduction?"

After quoting the article: "Break this section of the paper down for me and explain this process in simpler terms."

In general, we saw that undergraduate researchers engaged with ChatGPT in a variety of ways based on the ChatGPT-assisted reading protocol provided to them. Most students (82%, 9 of 11) followed the protocol's recommendation of providing an introduction prior to asking questions to allow ChatGPT to provide appropriate-level responses. By far the most common type of question asked was to provide a definition, with all students asking definition questions and a total of 31 definition questions being asked from all participants. This implies that a first barrier for undergraduate researchers reading literature is encountering unfamiliar words and concepts. As discussed in Round and Campbell's work, students reading scientific articles are likely to skim or skip unfamiliar or challenging terms, which prevents them from fully engaging with the literature.[2] By providing the students with a ChatGPT-assisted reading protocol, undergraduate researchers were given a useful way to obtain definitions for unfamiliar terms and to ask follow-up questions using their natural language. The undergraduate researchers could also ask ChatGPT to simplify language when needed, further lowering the barrier to engaging with the text.

Post-implementation survey

After completing the reading activity with the ChatGPT-assisted reading protocol, students were asked to complete a post-implementation survey about their experience using the reading protocol and their experience with ChatGPT. Eleven students completed the survey.

From the survey, 91% (10 of 11) of the students had used ChatGPT prior to this study. When asked how they used ChatGPT prior to this study in a free response question, 50% (5 of 10) reported using it to understand concepts from class and/or research, and 20% (2 of 10) reported being required to use it for class assignments. Other students reported using ChatGPT for non-academic related uses. This shows most students had familiarity with ChatGPT prior to using the ChatGPT-assisted reading protocol in this study.

The students were asked to write in free response items the biggest benefit and challenge of using ChatGPT while reading a scientific article. For the biggest benefit, the most common theme in response was that ChatGPT provides definitions and explanations in the context of the article (46%, 5 of 11), followed by clarity of explanation (36%, 4 of 11). Within their responses, students also expressed appreciation of the dynamic nature of interacting with ChatGPT (see second and third quotes) as opposed to traditional search engines:

"Having unknown words be defined in the context of the article"

"The biggest benefit of using ChatGPT was not only being able to receive an answer, but also being able to tune how concise I wanted that answer to be. It's also extremely helpful that I can ask a question in the context of a certain topic, and the computer will adjust accordingly."

"The biggest benefit was having things broken down to me in a way that I could actually understand. I feel that when searching things up, it's hard to find answers that actually explain without just reiterating what originally confused you."

When asked about the biggest challenge of using ChatGPT while reading scientific literature, the most common response was that it was a challenge to learn to phrase questions to get the desired response (46%, 5 of 11), and that the ChatGPT responses were sometimes too long (18%, 2 of 11):

"The biggest challenge is figuring out how to ask ChatGPT what I want to know."

"I feel like the biggest challenge using ChatGPT was providing enough background so that my question could be answered fully, coupled with the fact that I had to guess if I was providing enough context for a prompt."

Lastly, students were asked in a free response question if they would use ChatGPT to assist reading scientific journal articles in the future. All respondents (100%, 11 of 11) stated that they would use ChatGPT to assist them in reading articles going forward. Common themes in responses were that ChatGPT provides context/explains within the context of the article (46%, 5 of 11), and clarity of explanations and summaries (36%, 4 of 11):

"I'd would [sic] *expect to use ChatGPT in the future because it takes plenty of the guesswork out of contextualizing certain procedures and terms when reading papers on a research topic I am not familiar with."*

"I do expect to use ChatGPT in the future when reading scientific journal articles because it really does make the reading process much more easier, efficient, and effective. The program provides detailed, relevant, and real time explanations on questions and curiosities. It is also willing to word things differently and break down the information as much as necessary until you grasp the material. You can also provide it with your exact assumptions and thoughts on questions and material and it will respond to you and explain why you are right, wrong, or what it [sic] *missing."*

Conclusions

Based on the feedback from undergraduate researcher students in this study, the ChatGPT-assisted reading protocol was seen as beneficial. While subjects predominantly asked ChatGPT definition-type questions while reading the introduction of the article during the study, their feedback focused on the fact that, unlike traditional search engines, ChatGPT provides definitions and explanations with respect to the context of the article. The students also valued

the clarity and tunability of explanations provided by ChatGPT. The largest barrier to using ChatGPT was perceived to be formatting questions to elicit the desired response.

The finding that all of the students surveyed said they would use ChatGPT in future paper reading was especially interesting. The use of a chatbot while reading unfamiliar material may be a positive intervention to help students continue to engage with biophysics literature without becoming discouraged. If a tool like ChatGPT can help students quickly find the information they need to continue reading a paper and continue asking questions until they are satisfied with their understanding, they may be encouraged to continue reading papers on a regular basis as they continue to develop expertise. Especially compared to using a search engine to find material, which can require a level of expertise to correctly frame the question and find the answer, the interactive, back-and-forth nature of the chatbot may make it easier for students to minimize the disruptions to their reading and not feel overwhelmed when reading biophysics papers. In future investigations on using a ChatGPT-assisted reading protocol, additional training in effective question construction would be beneficial to further remove barriers for undergraduate student researchers to effectively engage with literature.

IRB

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Supplemental Information

The ChatGPT-assisted reading protocol is in the supplemental information.

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REFERENCES

(1) Pekrun, R.; Goetz, T.; Titz, W.; Perry, R. P. Academic Emotions in Students' Self-Regulated Learning and Achievement: A Program of Qualitative and Quantitative Research. *Educational Psychologist* **2002**, *37* (2), 91-105. DOI: 10.1207/S15326985EP3702_4.
(2) Round, J. E.; Campbell, A. M. Figure Facts: Encouraging Undergraduates to Take a Data-Centered Approach to Reading Primary Literature. *CBE—Life Sciences Education* **2013**, *12* (1), 39-46. DOI: 10.1187/cbe.11-07-0057.
(3) Forest, K.; Rayne, S. Incorporating Primary Literature Summary Projects into a First-Year Chemistry Curriculum. *Journal of Chemical Education* **2009**, *86* (5), 592. DOI: 10.1021/ed086p592.
(4) Dai, D. W.; Suzuki, S.; Chen, G. Generative AI for professional communication training in intercultural contexts: where are we now and where are we heading? *Applied Linguistics Review* **2024**. DOI: doi:10.1515/applirev-2024-0184 (acccessed 2024-08-15).
(5) Castillo-Martínez, I. M.; Ramírez-Montoya, M. S. Research Competencies to Develop Academic Reading and Writing: A Systematic Literature Review. *Frontiers in Education* **2021**, *5*, Systematic Review. DOI: 10.3389/feduc.2020.576961.

(6) Anne Gold, R. A., Karen McNeal. Undergraduates' Graph Interpretation and Scientific Paper Reading Shift from Novice- to Expert-like as a Result of Participation in a Summer Research Experience: A Case Study. *Scholarship and Practice of Undergraduate Research* **2021**, *5*, 7-19. DOI: https://doi.org/10.18833/spur/5/2/2.
(7) Lennox, R.; Hepburn, K.; Leaman, E.; van Houten, N. 'I'm probably just gonna skim': an assessment of undergraduate students' primary scientific literature reading approaches. *International Journal of Science Education* **2020**, *42* (9), 1409-1429. DOI: 10.1080/09500693.2020.1765044.
(8) Mitra, S.; Wagner, E. Introducing Undergraduates to Primary Research Literature. *Journal of Chemical Education* **2021**, *98* (7), 2262-2271. DOI: 10.1021/acs.jchemed.0c01439.
(9) Otto, J. L.; McDowell, G. S.; Balgopal, M. M.; Lijek, R. S. Preprint Peer Review Enhances Undergraduate Biology Students' Disciplinary Literacy and Sense of Belonging in STEM. *Journal of Microbiology & Biology Education* **2023**, *24* (2), e00053-00023. DOI: doi:10.1128/jmbe.00053-23.
(10) Alasadi, E. A.; Baiz, C. R. Generative AI in Education and Research: Opportunities, Concerns, and Solutions. *Journal of Chemical Education* **2023**, *100* (8), 2965-2971. DOI: 10.1021/acs.jchemed.3c00323.
(11) Hocky, G. M. Connecting molecular properties with plain language. *Nature Machine Intelligence* **2024**, *6* (3), 249-250. DOI: 10.1038/s42256-024-00812-y.
(12) Hocky, G. M.; White, A. D. Natural language processing models that automate programming will transform chemistry research and teaching. *Digital Discovery* **2022**, *1* (2), 79-83, 10.1039/D1DD00009H. DOI: 10.1039/D1DD00009H.
(13) White, A. D. The future of chemistry is language. *Nature Reviews Chemistry* **2023**, *7* (7), 457-458. DOI: 10.1038/s41570-023-00502-0.
(14) Alasadi, E. A.; Baiz, C. R. Multimodal Generative Artificial Intelligence Tackles Visual Problems in Chemistry. *Journal of Chemical Education* **2024**, *101* (7), 2716-2729. DOI: 10.1021/acs.jchemed.4c00138.
(15) Guo, Y.; Lee, D. Leveraging ChatGPT for Enhancing Critical Thinking Skills. *Journal of Chemical Education* **2023**, *100* (12), 4876-4883. DOI: 10.1021/acs.jchemed.3c00505.
(16) Tassoti, S. Assessment of Students Use of Generative Artificial Intelligence: Prompting Strategies and Prompt Engineering in Chemistry Education. *Journal of Chemical Education* **2024**, *101* (6), 2475-2482. DOI: 10.1021/acs.jchemed.4c00212.
(17) Yik, B. J.; Dood, A. J. ChatGPT Convincingly Explains Organic Chemistry Reaction Mechanisms Slightly Inaccurately with High Levels of Explanation Sophistication. *Journal of Chemical Education* **2024**, *101* (5), 1836-1846. DOI: 10.1021/acs.jchemed.4c00235.
(18) Young, J. D.; Dawood, L.; Lewis, S. E. Chemistry Students' Artificial Intelligence Literacy through their Critical Reflections of Chatbot Responses. *Journal of Chemical Education* **2024**, *101* (6), 2466-2474. DOI: 10.1021/acs.jchemed.4c00154.
(19) Exintaris, B.; Karunaratne, N.; Yuriev, E. Metacognition and Critical Thinking: Using ChatGPT-Generated Responses as Prompts for Critique in a Problem-Solving Workshop (SMARTCHEMPer). *Journal of Chemical Education* **2023**, *100* (8), 2972-2980. DOI: 10.1021/acs.jchemed.3c00481.
(20) Pence, H. E.; Hightower, G.; Forlenza, J.; Leonard, K.; McLellan, A.; Suero, A.; Amoah, B.; Mbow, M.; Borner, S.; Castillo, A.; et al. Using Generative AI Systems for Critical Thinking Engagement in an Advanced Chemistry Course: A Case Study. *Journal of Chemical Education* **2024**. DOI: 10.1021/acs.jchemed.4c00242.

(21) McGuire, S. Y. *Teach Students How to Learn: Strategies You Can Incorporate Into Any Course to Improve Student Metacognition, Study Skills, and Motivation*; Routledge, 2015. DOI: https://doi.org/10.4324/9781003447313.
(22) Kirchdoerfer, R. N.; Wang, N.; Pallesen, J.; Wrapp, D.; Turner, H. L.; Cottrell, C. A.; Corbett, K. S.; Graham, B. S.; McLellan, J. S.; Ward, A. B. Stabilized coronavirus spikes are resistant to conformational changes induced by receptor recognition or proteolysis. *Scientific Reports* **2018**, *8* (1), 15701. DOI: 10.1038/s41598-018-34171-7.
(23) Saldaña, J. *The Coding Manual for Qualitative Researchers*; SAGE Publications Ltd, 2021.