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Research Article

Podcasts and Papers: Using AI to Engage Undergraduates in Scientific Literacy in Biology

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ABSTRACT

Purpose of the study: Artificial Intelligence (AI) is emerging as a valuable tool for science education, for both students and instructors. This study was conducted to investigate the efficacy of using AI-generated podcasts to introduce undergraduates to primary scientific literature as a teaching pedagogy.

Methodology: Google NotebookLM was used to generate audio podcasts on ten different scientific journal articles for an undergraduate ecology course. Students were surveyed on how engaging, informative, and helpful podcasts were, and whether they helped introduce them to the research article. Data were collected from Likert-scale questionnaires and short responses and analyzed both quantitatively and qualitatively.

Main Findings: The majority of students found AI-generated audio podcasts an engaging and effective learning method for increasing science literacy and understanding. No change was noted across the class in student perceptions of podcasts, indicating that the majority of students found AI podcasts helped them learn about scientific research, with ~35% not realizing the podcast was AI. These findings reveal the potential to increase science literacy through our methodology if incorporated across various fields of science education.

Novelty/Originality of this study: This study provides evidence that AI-generated podcasts can be used as a new method to introduce biology students to peer-reviewed scientific articles. Other educators can use similar free audio podcasts across subjects to engage undergraduate students in science. The findings add to our body of knowledge on AI and on how educators can utilize podcasts as a powerful pedagogical tool for teaching science.

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1. INTRODUCTION

The communication of science has historically fallen short compared with other art and entertainment fields, especially when conveying its importance to a general audience, including students. Engaging undergraduate students in the sciences can be challenging, especially in teaching and promoting science literacy [1]-[3]. Among the many methods implemented by faculty to increase science literacy is the direct involvement of undergraduates in scientific research [4]-[9]. However, not all educators have the ability, resources, or funds to conduct extensive research with undergraduates, especially at larger institutions. Moreover, digital social media are becoming widely used platforms for communicating science to a broad audience beyond peer-

reviewed scientific journals [10]-[12], highlighting the need for science education to adapt to the increasingly digital landscape. One method for engaging undergraduates in science that may increase scientific literacy is the use of audio podcasts.

The field of education is among the many areas where traditional methods can be augmented as technology becomes more widely available, as the tools of the trade change, both in and out of the classroom. Podcasting has been utilized as a learning medium to disseminate research findings and educational concepts [13]-[17]. The use of podcasting can provide students with a less rigorous yet informative learning method for effectively introducing peer-reviewed science journal articles within the framework of a science class, as biology students may lack the background to approach published science with the high level of understanding expected in graduate school. While podcasting has been increasingly more popular as a media in the sciences, including the fields of ecology and evolutionary biology [18]-[22], few if any studies have assessed the potential for artificial intelligence (AI) generated podcasting as a teaching tool in biology or ecological science coursework.

The use of AI in education has grown as an approach to learning, both among students and science faculty. The use of AI-generated podcasting has recently been explored as a means of disseminating published medical literature [23]-[25]. Google's NotebookLM and its audio overview function allow the generation of an AI podcast with two virtual "hosts" taking a "deep dive" and discussing document uploads [26]-[29], and have the potential to create comprehensive instructional content for students that both engages and informs, and may increase science literacy. Although previous research has clearly shown the potential for AI to be utilized as a pedagogical tool, there exists a research urgency and gap in our overall knowledge on how successful AI-generated podcasts can be incorporated into education programs, especially in the sciences, where students may often struggle with scientific literacy, i.e., undergraduates reading and discussing peer-reviewed scientific journal articles.

Herein, we used AI-generated podcasts as a complementary method to engage and introduce students to specific research papers in ecology and conservation. Our overall goal was to assess whether students perceived that incorporating podcasts helped them learn about research and science before reading a published peer-reviewed scientific article. Specifically, we selected 10 research articles, produced an AI podcast using NotebookLM, and surveyed undergraduates on whether the podcasts were engaging and whether they helped introduce and inform them about the research presented in the peer-reviewed journals. Therefore, our research objectives were to quantitatively assess students' perceptions of AI-generated podcasts using a series of survey questions related to students' comprehension of a scientific article, the importance of the article, and the overall effectiveness of these podcasts in engaging and promoting student learning.

2. RESEARCH METHOD

This research was conducted as part of an undergraduate, upper-level in-person Ecology Course consisting of 23 students. The course was designed for both biology and environmental science majors. A total of ten peer-reviewed scientific research papers were selected across a wide range of scientific topics pertaining to ecology, environmental science, and conservation biology (Table 1). For each paper, it was uploaded into the free version of Google NotebookLM as a PDF document. This software uses Google's Gemini 2.0 Flash AI Model and is a freely available artificial intelligence learning tool. This process involved using the "Create New Notebook" function, then uploading the PDF of the research article. Next, in the "Studio" option, we selected the "Audio Overview" function. This process took ~10-15 minutes to generate. The audio file was then downloaded, converted to an mp3 file, then loaded onto the Canvas LMS. Students were instructed to first listen to the podcast, then read the research paper weekly as part of the Ecology course (~1 paper and associated podcast per week). Papers were discussed in class first in groups, then briefly as an entire class. Following this in-class discussion, students filled out an anonymous survey for each podcast and associated paper. At the end of the course an additional final survey was filled out to assess the student's perspective on podcasts overall. Students were never informed during the course that the podcast and podcasters were AI.

The weekly survey (associated with a specific scientific paper) consisted of four total questions, Q1: "Did you prefer listening to a podcast in addition to reading the scientific paper?", Q2: "On a scale of 1 to 6, did the podcast help you understand the scientific article?", Q3: "On a scale of 1 to 6, did the podcast help you relate the importance of the scientific article to Ecology or Science?", and Q4: "Additional written comments or Feedback on the podcast". Responses to Q1 was either a Yes or No option, responses to Q2 and Q3 were on the following Likert Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Slightly Disagree, 4 = Slightly Agree, 5 = Agree, 6 = Strongly Agree. Finally, responses to Q4 were written comments typically in three to four sentences.

The Final Survey (FS), given out at end of the course assessing the activity overall consisted of several final survey questions, including FSQ1: "When did you realize the podcasters were AI?, with the answer options as follows. This FS also consisted of FSQ2: "How often do you listen to podcasts?", with the answer options of "never", "once/twice a month or rarely", "once a week", or "several times a week or very often". Additional questions on the FS consisted of FSQ3: "Do you ever listen to Science or Nature podcasts?" (responses as Yes or

No), and also FSQ4: "What type of podcast do you listen to?" with responses written in by students or open response. A Final Survey question, FSQ5: "Across the various papers and podcasts this semester, how exactly did listening to the podcast allow you to understand biology, ecology, and science?", was included as an final open response question to allow students to answer a reflective question for the activity as a whole, not linked to a specific paper or article. Lastly, FSQ6: "Was podcasting an enjoyable method for science communication?", and FSQ7: "Should podcasting be used as a tool to communicate science to undergraduate biology majors?", were also given in the Final Survey to assess how effective students perceived that the podcasts were able to be used to communicate science. Responses to FSQ6 and FSQ7 were either a Yes or No. Surveys given to student participants and research was approved by the Wingate University Research Review Board (protocol #SU90122).

Data was entered from surveys in MS Excel by authors, including written feedback comments. Therefore data sampling was collected from responses to hand written surveys, compiled by authors prior to data analysis. A limitation of this study does include a lack of a comparison group or specific measure of literacy gains, as the students were not directly informed of the AI nature of the podcast and self-reported their survey responses, due to the experimental design of this study. Responses to Q2 and Q3 were combined across all ten papers, then analyzed using a Kruskal-Wallis Test in R version 4.1.0, using the function "kruskal.test" to assess whether student reponses varied across the ten podcasts. Moreover, a X^2 analysis was run for responses to Q2 and Q3 to compare student responses for podcast increasing understanding and importance of research. Responses to the additional final survey were also analyzed in R, using "chisq.test" function. For all other questions, descriptive statistics and percentages are reported. For all statistical tests, the level of significance was set a $p < 0.05$. We calculated Cronbach alpha value in R version 4.1.0, using the Cronbach.alpha() function from package ltm, to report on reliability value of survey questions Q2 and Q3.

Table 1. Titles of Papers with Journal and Year of Publication chosen for this study and corresponding Podcasts Titles and Times (minutes and seconds)

Article Title/Journal/Year	Podcast Title/Time
1: What Darwin's Finches can Teach us About the Evolutionary Origin and Regulation of Biodiversity. *Bioscience, 2003*.	1: Beyond Beaks: Darwin's Finches and the Shocking Fast Evolution of Life. *14:04*.
2: Experimental Zoogeography of Islands: The Colonization of Empty Islands. *Ecology, 1969*.	2: Island Resilience: How Life Bounces back from Ground Zero. *11:56*.
3: Bats and Wetlands: Synthesising Gaps in Current Knowledge and Future Opportunties for Conservation. *Mammal Review, 2021*.	3: Vanishing Wetlands, Flying Blind: The Critical Bat Connection we're missing. *18:13*.
4: The Detection of Aquatic animal species using environmental DNA: a review of eDNA as a Survey Tool in ecology. *Journal of Applied Ecology, 2014*.	4: eDNA Revolution: How Genetic Breadcrumbs are Replacing Nets and Traps for Aquatic Species Monitoring. *15:05*.
5: Multiple Lines of Evidence Suggest the Persistence of the Ivory-billed Woodpecker (*Campephilus principalis*) in Louisiana. *Ecology and Evolution, 2023.*	5: The Ghost Bird Flies Again?: New Evidence for the Elusive Ivory-billed Woodpecker. *16:42*.
6: Time for a Change: Dynamic Urban Ecology. *Trends in Ecology and Evolution, 2012*.	6: Ecological Clock Ticking: Why the Dynamic Urban Framework is Essential for Saving City Nature. *16:15.*
7: Ecology and Impacts of White-Nose Syndrome on Bats. *Nature Reviews Microbiology, 2021*.	7: White-Nose Syndrome: Ecology, Impacts, and Conservation in Bats. *13:48*.
8: Biological Annihiliation via the Ongoing Sixth Mass Extinction Signaled by Vertebrate Population Losses and Declines. *Proceedings of the National Academy of Sciences, 2017*.	8: Biological Annihilation via Ongoing Sixth Mass Extinction. *16:10*.
9: Experiments are Needed to Quantify the Main Causes of Insect Decline. *Biology Letters, 2023*	9: Experiments Quantify Main Causes of Insect Decline. *13:54*.
10: Filial Cannibalism Leads to Chronic Nest Failure of Eastern Hellbender Salamanders (*Cryptrobranchus alleganiensis*). *The American Naturalist, 2023.*	10: Hellbender Cannibalism and Reproductive Failure in Degraded Habitats. *15:56*.

Table 1 arranged in order the podcasts and papers were read by students thoughout the course.

3. RESULTS AND DISCUSSION

Student perceptions of podcasts were positive. Across all surveys on 10 podcasts and associated papers, for Q1, 93.9% of students responded "*Yes*" that they "*prefer listening to podcast in addition to reading the scientific article*", with only 6.1% stating "*No*", indicating the vast majority showed a preference for inclusion of a podcast when assigned to read a scientific article. Responses to Q2 and Q3 were statistically significant, X^2 = 106.6, df = 5, $p < 0.001$, and X^2 = 71.1, df = 5, $p < 0.001$, respectively (Figure 1, Figure 2). When combined these results indicate students largely agreed that podcasts both helped them to understand the article and relate the importance of article to science. To compare student responses across all podcasts, responses to the Q2 ("*Did podcast help you understand scientific article?*"), the Kruskal-Wallis test was not significant H(9) = 8.6427, p = 0.471, Median = 5, Minimum = 2, Maximum = 6, indicating that perceptions across the ten papers were consistent. In other words, there was no trend for an increase or decrease in student perception of how helpful podcasts were across the course in that they continued to give positive feedback for all podcasts related to scientific papers. A similar result was found for Q3 ("*Did podcast help you relate the importance of scientific article to Ecology/Science*?"), H(9) = 9.07, p = 0.431, Median = 5, Minium = 3, Maximum = 6. This also indicated that student responses were similar across all podcasts associated with papers throughout the course. Cronbach's alpha value was calculated as 0.813, indicating good internal consistency across survey questions. Written responses to Q4 are included in Table 2 and are largely positive for inclusion of podcasts as an initial learning tool.

For the Final Survey Questions, responses were similarly positive for student perceptions of podcasts when asked to reflect on the podcast as a learning tool across the semester course. Results for FSQ1, were not significant, X^2 = 2.56, df = 3, p = 0.464, indicating there was high variability in responses, with 34.8% not realizing the podcasts were AI generated and only 30.4% realizing it was AI right away by the first podcast. Several students responded that they realized podcasts were AI by the first few papers to last few papers. Responses for frequency students listen to podcasts was also variable with 13% responding "*never*", 35% responding "*once/twice a month*", and 26% and 26% responding either "*once a week*" or "*several times a week or very often*", respectively. For FSQ3, 56.5% responded "*No*" (13) and 43.5% responded "*Yes*" (10), if they ever listen to science or nature podcasts. Responses to FSQ4 for respondents that answered "*Yes*" to FSQ3, were variable, and included podcasts across diverse topics such as Criminal, History, Pop Culture, Horror, Nature, Science, Comedy, Health, and Education. Written responses to FSQ5 are included in Table 2, and were largely positive. Moreover, responses to FSQ6 and FSQ7 were 100% "*Yes*", if "*podcasting was an enjoyable method for science communication*" (FSQ6), and "*should podcasting be used as a tool to communicate science to undergraduate biology majors"* (FSQ7). When combined, these results indicate that students had a preference for listening to podcasts, found podcasts helped them understand scientific articles, and provided a framework for placing the scientific research in context for importance.

Table 2. Written responses to Survey Questions regarding Podcasts and Papers.

Survey Question	Representative Reponses
Q4: "Additional Comments on Podcast"	"Podcast helped with interpretation", "Podcast was great, it provided a great preview of the article", "The podcast helped me understand the main points of the paper and an overall view of the research", "The podcast made the paper easier to understand", "I like the podcast because it makes the paper more digestable" , "The podcast helped me get another person's perspective on the research, which helped me think about the main idea of the paper", "The podcast helped breaking down the methods of the paper in more simple terms", "The podcast made me feel a part of the conversation, and it let me actually understand the big picture", "I liked how the podcast felt like a casual conversation", "I listened to the podcast before reading the article and found it effective in helping me to understand the main points of the scientific article", "The podcast provided a good foundation for the paper, it makes the common person able to understand the topic and importance, which can help be engaged when reading the paper", "It made it easier to understand the science"
FSQ5: "Across the various podcasts this semester, how exactly did listening to the podcast allow you to understand biology, ecology, and science?"	"I'm more of an auditory learner so the podcasts made it easier to understand and digest the research paper", "Podcasts were great, they made science more understandable and emphasized the main points of the paper", "the podcasts helped me to understand the context of the scientific paper since it was in conversation form"

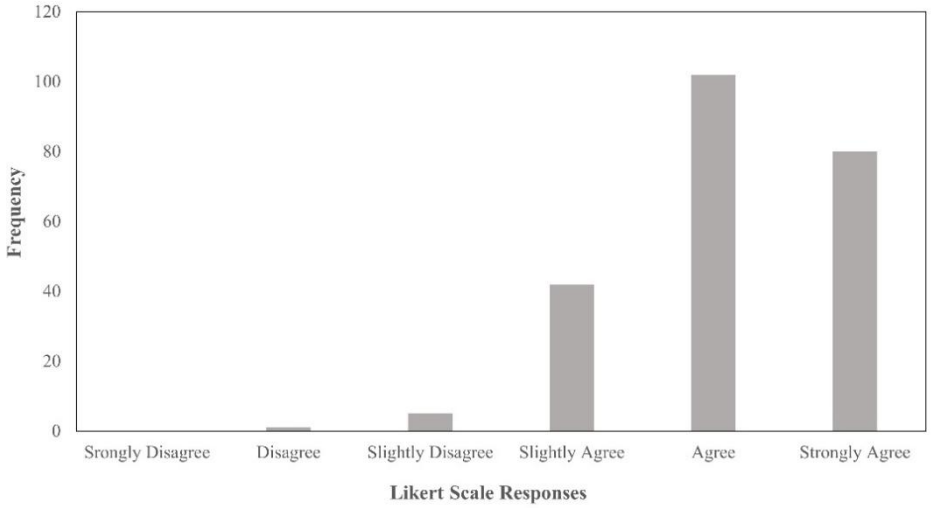

Figure 1. Student Responses across all ten podcasts for Q2: "On a scale of 1 to 6, Did the podcast help you understand the article?"

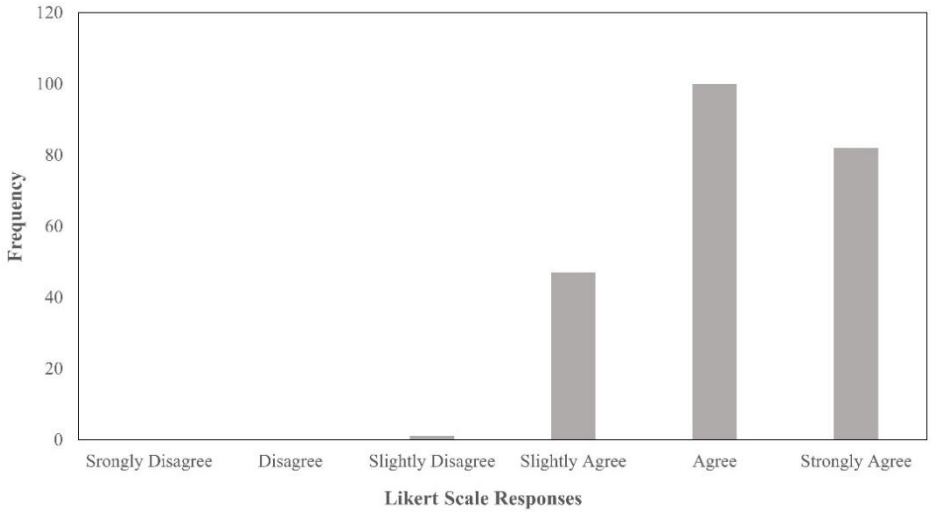

Figure 2. Student Responses across all ten podcasts for Q3: "On a scale of 1 to 6, Did the podcast help you relate the importance of the scientific article to Ecology or Science?"

Representative responses for Q4 that were positive included "*The podcast brought up cool facts that made me interested in learning more.",* and "*The podcast helped to keep me engaged on the main idea of the paper without getting bored.*", as well as "*The podcast gave me a better understanding of the research over just reading the paper.*". Several responses indicated how the podcast enabled students to be introduced to topic of research with "*The podcast gets my mind on the topic and ready to read.*", and "*The podcast provides a good base for the paper, without it, the papers can sometimes be hard to digest*.". Several comments by students mentioned the ability of the podcast to provide analogies and a conversational tone ideal for a wide audience, including "*The podcast simplifies the paper and makes it easier for the layperson to understand*.", and "*The podcast provides great analogies.*", and "*The podcast summarizes the article with less scientific jargon*.". Some responses were mixed such as "*The podcast was nice, it is a change of pace and helps to give some context, but I could get by without it*.". Interestingly, some responses indicated that students believed the AI was a real person and commented on wanting different podcasters with "*The podcast was helpful, it might be nice to have some podcast variety, like different people or a different podcast*.". Alternatively, some students responded "*I did not gain much from the podcast, I prefer reading the article.",* and also "*The podcast didn't really help and I felt it was very casual and not formal*.", indicating that some students feel a podcast is perhaps not needed and reading scientific papers are adequate. Some students commented on the ability of podcast as an audio medium to increase learning, "*The podcast really helps me understand the paper as it allows me to focus on what is being said not just what is being read.*". There may have been some variation across papers and podcast for students with some responses indicating variability in how helpful a specific podcast was for a research paper with "*The*

podcast was not as good as others." and "*The podcast wasn't as interesting.*". However, the vast majority of student responses and comments were positive when asked about the podcast in relation to each scientific paper. When taken together, the student responses and results indicate that podcast can provide a valuable tool to engage and inform students on science literacy. Future work by science educators should investigate issues related to ethics and the use of AI generated content not just in education but also in science, as students in this study did not all initially realize the podcast were AI generated [30]-[35]. Therefore, it remains to be seen if student perceptions remain positive regarding AI generated podcast if they are explicitely informed of this prior to relying on it as a media for science education. Follow up studies could compare selective "real" podcast alongside AI generated podcast and assess student engagement. Limitations of the experimental design of our study includes the students' self reporting survey data, lack of comparison group, and finally specific assessment to measure science literacy. However, this study still provides novel data on AI generated podcast which can lead to future research using AI generated podcast as a teaching tool among science educators [36]-[40]. Moreover, the results of the data in our study on the use of AI generated podcast clearly show how not only podcast can be perceived by students as an effective learning media, but alongside other studies, illustrate that teachers can successfully generate interest among students and elevate the learning experience via discussion. Subsequently, this area of study is only recently emerging as a novel teaching method, as such researchers should continue to incorporate this readily available pedagogical tool to disseminate science and make it more accessible for undergraduates in science courses.

The findings demonstrate that students hold highly positive perceptions toward the integration of podcasts as a complementary learning tool for understanding scientific articles. An overwhelming majority of students (93.9%) expressed a preference for listening to podcasts alongside reading scientific papers, indicating strong acceptance of multimodal learning approaches. The statistically significant results for Q2 and Q3 (χ^2 = 106.6 and χ^2 = 71.1; $p < 0.001$) further confirm that podcasts not only enhance comprehension of scientific articles but also help students contextualize the importance of research within broader scientific domains such as ecology. The non-significant Kruskal–Wallis test results across the ten podcasts suggest consistency in student perceptions, indicating that the effectiveness of podcasts was stable regardless of variations in content. Additionally, the Cronbach's alpha value of 0.813 reflects strong internal consistency, reinforcing the reliability of the survey instrument. These findings collectively suggest that podcasts function as an effective scaffold, enabling students to bridge the gap between complex scientific texts and meaningful understanding.

From a pedagogical perspective, the effectiveness of podcasts can be attributed to their ability to present scientific information in a more accessible, conversational, and engaging format [41]-[44]. Students' written responses reveal that podcasts facilitated comprehension by simplifying complex terminology, providing analogies, and offering an overview of key concepts before engaging with dense academic texts. This aligns with cognitive learning theories that emphasize the importance of multimodal input and scaffolding in enhancing comprehension, particularly for novice learners encountering scientific literature for the first time [45]-[48]. Moreover, podcasts appear to support diverse learning preferences, particularly auditory learners, by allowing them to process information in a format that aligns with their cognitive strengths. The conversational tone and narrative structure of podcasts also contribute to increased engagement, making students feel more connected to the material and less intimidated by scientific discourse.

Interestingly, findings from the final survey indicate variability in students' awareness of the AI-generated nature of the podcasts, with only 30.4% recognizing this from the outset. Despite this, 100% of students agreed that podcasting is an enjoyable and valuable method for science communication, and that it should be incorporated into undergraduate biology education. This suggests that the perceived effectiveness of podcasts may be more strongly influenced by their pedagogical design and delivery rather than their origin (human vs. AI-generated). However, this also raises important considerations regarding transparency and ethics in the use of AI-generated educational content. The fact that some students believed the podcasts were created by real individuals highlights the need for clearer communication about the role of artificial intelligence in educational settings [49]-[51].

The novelty of this study lies in its empirical exploration of AI-generated podcasts as a pedagogical tool for enhancing science literacy. While prior research has examined podcasts in education, this study uniquely investigates the integration of AI-generated audio content in supporting the comprehension of peer-reviewed scientific literature. Furthermore, the study combines quantitative analysis with qualitative student feedback to provide a comprehensive understanding of how podcasts influence learning processes. This contributes a new perspective to the emerging field of AI-assisted education, particularly in science communication and literacy development. The implications of these findings are significant for educators, curriculum designers, and higher education institutions. Practically, the results suggest that podcasts can be effectively integrated as a preparatory or supplementary learning tool to help students "get the gist" of scientific articles before engaging in deeper reading. This approach can reduce cognitive overload, increase engagement, and improve overall comprehension. For educators, incorporating podcasts into course design offers an opportunity to diversify instructional strategies and accommodate different learning styles. At the institutional level, the use of AI-

generated podcasts provides a scalable and cost-effective solution for enhancing science communication, particularly in large classes or online learning environments.

Despite its contributions, this study has several limitations. The reliance on self-reported survey data introduces the possibility of response bias, as student perceptions may not fully reflect actual learning outcomes. The absence of a control group limits the ability to draw causal conclusions regarding the effectiveness of other learning methods. Additionally, the study does not include direct assessments of science literacy gains, which would provide stronger evidence of learning impact. Variability in podcast quality and student preferences also suggests that not all podcasts may be equally effective, highlighting the importance of careful instructional design. Based on these limitations, several recommendations for future research are proposed. Future studies should incorporate experimental or quasi-experimental designs with control groups to more rigorously evaluate the causal impact of podcasts on learning outcomes. Including objective measures of science literacy, such as comprehension tests or analytical writing tasks, would strengthen the validity of findings. Comparative studies examining AI-generated versus human-produced podcasts could provide deeper insights into the role of authenticity and perceived credibility in learning. Additionally, future research should explore ethical considerations related to AI in education, particularly regarding transparency, authorship, and student trust. Expanding this line of inquiry across different disciplines and educational levels would also enhance the generalizability of findings.

4. CONCLUSION

Overall, this study concludes that podcasts—particularly those supported by AI—serve as an effective, engaging, and complementary pedagogical tool for introducing students to scientific literature and enhancing science literacy. Students perceive podcasts as helpful in providing accessible entry points into complex academic texts, enabling them to grasp key ideas and contextual relevance before engaging in deeper reading. However, podcasts should not be viewed as a replacement for peer-reviewed articles, as essential elements such as figures, tables, and detailed data interpretation remain integral to scientific understanding. Rather, podcasts function most effectively as a scaffold that bridges initial comprehension and more rigorous analytical reading. The findings also highlight the growing potential of AI in transforming science education, particularly through the generation of customized, efficient, and scalable learning resources such as audio summaries and, potentially, short educational videos. Despite these promising outcomes, the study is limited by its small sample size and the inability to track individual learning progression over time due to anonymous survey design. The implications of this study are multifaceted. Pedagogically, educators are encouraged to integrate AI-generated podcasts as introductory learning media to reduce students' cognitive barriers when approaching scientific literature, thereby fostering greater engagement, confidence, and comprehension. Instructional strategies should combine audio-based learning with traditional reading and discussion to ensure a balanced and comprehensive understanding of scientific content. From an assessment perspective, there is a need to develop more systematic and measurable approaches to evaluate improvements in students' science literacy, including longitudinal tracking of learning outcomes and perceptions. Additionally, the comparison between AI-generated and human-produced educational content should be further explored to ensure transparency, quality, and effectiveness. At a broader level, this study underscores the importance of preparing educators and students to critically engage with AI as an evolving tool in education, including addressing ethical considerations, potential overreliance, and issues of accuracy. Future research should expand the scope to larger and more diverse populations, investigate multimodal AI applications such as video-based summaries, and examine long-term impacts on students' analytical and critical reading skills. Ultimately, the integration of AI-generated podcasts represents a promising step toward making scientific knowledge more accessible, reducing barriers to understanding, and fostering a more inclusive and technologically enriched science learning environment.

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AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Data Curation, Writing-Original Draft Preparation, & Visualization, SU and MR; Writing – Review & Editing, SU and MR

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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