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RESEARCH ARTICLE

Effects of Popular Science Writing Instruction on General Education Student Attitudes Towards Science: A Case Study in Astronomy

Briley L. Lewis[1,2,*], K. Supriya[3,4], Graham H. Read[5,4], Kaitlin L. Ingraham Dixie[3,4], Rachel Kennison[3,4] and Anthony R. Friscia[6,2]

[1]Department of Physics and Astronomy, UCLA, Los Angeles, CA 90095 USA ; [2]Cluster Program, UCLA, Los Angeles, CA 90095 USA ; [3]Center for Education Innovation and Learning in the Sciences (CEILS), UCLA, Los Angeles, CA 90095 USA ; [4]Center for the Integration of Research Teaching and Learning (CIRTL), UCLA, Los Angeles, CA 90095 USA ; [5]Molecular Biology Institute, UCLA, Los Angeles, CA 90095 USA ; [6]Department of Integrative Biology and Physiology, UCLA, Los Angeles, CA 90095 USA

[*]blewis@astro.ucla.edu

Abstract

For many students, introductory college science courses are often the only opportunity in their formal higher education to be exposed to science, shaping their view of the subject, their scientific literacy, and their attitudes towards their own ability in Science, Technology, Engineering, and Math (STEM). While science writing instruction has been demonstrated to impact attitudes and outlooks of STEM majors in their coursework, this instructional strategy has yet to be explored for non-majors. In this work, we investigate student attitudes towards STEM before and after taking a writing-intensive introductory astronomy course. We find that students cite writing about science as beneficial to their learning, deepening their understanding of science topics and their perspective on science as a field and finding writing to be a "bridge" between STEM content and their focus on humanities in their majors. Students also report increased perceptions of their own ability and confidence in engaging with STEM across multiple metrics, leaving the course more prepared to be informed, engaged, and science literate citizens. This case study illustrates that writing pedagogy may be a promising technique for further investigation.

Keywords: Introductory Courses; Writing Pedagogy; Higher Education; Science Writing; Attitudes towards STEM

1 Background

In the past few years, disbelief in science has been an issue of national news, especially during the COVID-19 pandemic, and the general public's attitudes towards science are often filled with misconceptions, leading to polarization in beliefs and mistrust of scientists (Rutjens et al., 2018; Kreps and Kriner, 2020). Yet, at the same time, science is respected as a career and often seen as requiring innate talent and intelligence, especially in the physical sciences; there are many inaccurate stereotypes of scientists that are pervasive in society as well, such as the "lone male white genius" trope (Bruun et al., 2018). These negative attitudes and misconceptions about Science, Technology, Engineering, and Math (STEM) fields naturally lead us to ask – how do students develop these beliefs? How has their science education failed to address these beliefs, and what can we do to make a positive impact on students' attitudes towards science?

For many students, their main exposure to science in higher education is an introductory course that fulfills a general education (GE) requirement. Research has shown that interventions to teach scientific literacy in science courses for non-science majors (e.g. introductory GE courses) can be quite effective in their ability to engender positive attitudes towards science and build science literacy skills (Wittman, 2009; Hobson, 2008). Links between increased science literacy and improved attitudes towards science in introductory astronomy courses for non-majors (Wittman, 2009; Duncan and Arthurs, 2012) have been well-established in the literature and provide support that attitudes and beliefs about science can be altered by effectively teaching science literacy.

Interventions involving current research and science writing are well established in the literature for STEM students, but there is less information available for these techniques in an introductory non-major/GE course. Studies show that engaging with recent science literature exposes STEM students to active research questions and provides real-world motivation to learn the content, making it clear how the course is relevant to their careers (Donohue et al., 2021). More generally, research has shown that providing students with a real-world writing task is incredibly impactful, leading to changes in student beliefs about science and deepening student learning (Kiefer and Leff, 2008). Additionally, STEM students benefit from broader perspectives that can be developed by targeted interventions in discipline-based reading and writing skills. These writing skills help students develop broader perspectives on their work in science, put science concepts into context, and learn how to contribute to scientific discourse (Sørvik and Mork, 2015; Szymanski, 2014). Writing is a prime example of an active learning strategy, which has been shown to promote inclusivity in many disciplines (Penner, 2018; Theobald et al., 2020). Science writing has also been shown in the literature to be an effective tool for improving attitudes towards science in STEM students, but this result has not yet been extended to non-major/GE students (Pelger and Nilsson, 2016; Erkol et al., 2010).

The goal of this project is to demonstrate that popular science writing has the potential to be an effective tool for improving student attitudes towards science and increasing student engagement with science in an introductory general education science course. That is, students in such a course generally do *not* intend to major in a STEM discipline, and are taking the course to fulfill a science requirement amidst their major coursework in the humanities. In this work, we report qualitative information gathered on student experiences and attitudes in a uniquely writing-focused introductory GE astronomy course for non-STEM students.

Data collected in this course cover students' interest in science/astronomy, their perception of the benefits and personal relevance of science, their perception of their own ability to engage with and communicate about STEM, and their perception of stereotypes of scientists such as STEM fields requiring innate talent. The factors measured within this work all have a basis in the literature as desirable outcomes for students in an introductory non-major STEM course, or as factors that improve student learning. Student interest in a subject has been linked to student engagement and learning in a course – naturally, if students are interested and curious about a topic, they are more likely to apply themselves to learning about it (Renninger and Hidi, 2015). Thus, one measure of a "successful" introductory science course is an increase in student interest in the subject. Additionally, increased student understanding of the benefits of learning the subject matter at hand and of the relevance of the material to their lives is key for increasing student buy-in (Cavanagh et al., 2016; Wang et al., 2021; Stuckey et al., 2013; Newton, 1988; Frymier and Shulman, 1995).

When discussing student attitudes about science, there are three main categories of thought about STEM fields we want to influence: what they think of *scientists*, how students think of the *benefits* of learning science, and how they think of the *relevance* of science to their lives / society. Many introductory GE science courses aim to promote diverse representation of current STEM practitioners and positively influence the views of students about scientists (Yuretich et al., 2001). This is in response to persistent stereotypes of scientists, especially for the physical sciences like physics and astronomy. Stereotypes regarding gender, age, ethnicity, and more exist, such as the idea that stereotypically female gender roles aren't compatible with the skills and personality of a scientist (Carli et al., 2016), that scientists are generally older white men (Ferguson and Lezotte, 2020; Bruun et al., 2018; Losh, 2010), and that being a scientist requires a high degree of innate talent (Leslie et al., 2015). The benefits of science are not only important for student buy-in, but also buy-in to public funding for science (Muñoz et al., 2012).

Relevance is also often cited as a key metric of good science teaching (Newton, 1988) – a 2013 review even described that the literature states "making science learning relevant both to the learner personally and to the society in which he or she lives should be one of the key goals of science education" (Stuckey et al., 2013). As perceptions of science courses became more negative in the 2000s, studies cited "irrelevance" as a student concern about their science education, and as a result there was a large push to connect science to students' lived experiences and better motivate them to learn about science (Stuckey et al., 2013; Holbrook, 2003, 2005; Gilbert, 2006; Dillon, 2016). Although relevance is often ill-defined in education studies, Stuckey et al. (2013) suggests three dimensions: relevance in preparing students for careers, relevance for understanding scientific phenomena, and relevance for students becoming effective future citizens. In this study, we asked students about the broad concept of relevance, to which students responded with their personal interpretations; students were not guided with this definition of relevance, but we find it useful as a framework to investigate themes in student responses as discussed in Section 2.

There are also four tasks that we use as a basis for judging student ability/confidence in science-related activities, all related to activities they have practiced during the course: reading primary literature, reading science news, explaining science concepts, and writing about a scientific discovery. High amounts of technical jargon often make it difficult for students to read primary literature in the science, with even graduate students reporting apprehension reading research articles (Lewis, *in prep*). Yet, despite research literature's inaccessibility, K-12 and undergraduate classes seek to incorporate cutting-edge research and even primary sources into their curriculum to increase some aspect of relevancy and real-world applicability (Nieves, 2020; Eales and Laksana, 2016). Understanding the role of scientific publishing, and its reliability as a source, is also key to public perceptions of science (Miller, 2004). Explaining science concepts also helps with building students' conceptual understanding and intuition for content, whether through verbal explanations such as in tutor learning or through the written word as in writing-to-learn exercises, and empowers students to discuss science in their lives more generally (Roscoe and Chi, 2007; Ackerman, 1993).

Additionally, in science writing and journalism, tackling research papers is one of the first – and often most challenging – steps in the writing process that a new writer has to learn (Witze, 2020). There are clearly many benefits to exposing students to primary sources in scientific research, but there is also the distinct challenge of approaching a genre written for an expressly technical audience. We expect reading science news and informally explaining concepts to be more accessible to students, and more likely to be activities they continue in their daily lives. Generally, we expect inexperienced writers to find analysis of technical sources challenging, but we expect them to have an easier time expressing things more colloquially.

We hypothesize that a science writing intervention in this introductory GE astronomy course will have a positive effect on non-major students' perceptions of science. Based on experience with a prior iteration of the course in this study, we believe that science writing instruction will help students in the course, a group comprised of diverse non-STEM majors, use writing as a method to connect science concepts to their own interests and their humanities coursework, and that writing as a real-world task will engender a belief that students are capable of engaging with scientific concepts. Since the data in this work were collected in a small, unique, and self-selected group of students, this work serves as a case study into how writing instruction affected student perceptions in specific circumstances; any generalization of the results should be done with caution, and the extension of similar writing pedagogy structures into other introductory STEM classes could provide important insight into the generalizability of these results.

In Section 2, we detail the study population as well as the design of the course and assessments. In Section 3, we report student responses to open-ended survey questions both before and after the course, as well as information from student interviews. Finally, in Sections 4 and 5, we offer our analysis and interpretation of student responses, explore the implications of these results, and offer recommendations for writing-based science education and future work on this topic.

2 Methods

2.1 Study Population

Student participants were all first-year undergraduates at a large public university in the United States at the time of the study. These students were enrolled in a seminar on astrobiology and science journalism. This seminar is part of a program offered only to first-year students that provides a range of year-long (three academic quarters) courses that cover "Big Ideas," and all fulfill various general education (GE) requirements. Each year, this program offers ten of these multi-disciplinary courses, drawing faculty and teaching assistants from multiple departments. These courses are open only to incoming freshman students, and about one-third of the university's freshman class enrolls in a course through this program.

The first two quarters of these courses are "traditional" lecture/discussion section courses – students attend lecture with the entire class two or three times a week and a smaller discussion section of 20 students led by a Teaching Assistant once a week. During the third quarter of the course, students choose a seminar to take, taught by a member of the teaching team which delves deeper into a related topic in a small (20 student) seminar course. Specifically, student participants in this study were enrolled in the year-long program focusing on the evolution of life and the Universe. The teaching team for this course includes an astronomer, planetary scientist, and two biologists (a paleontologist and an evolutionary biologist), and covers the history of the universe from the Big Bang to the evolution of humanity, including topics on the formation of the elements, planetary geology and biological evolution. The emphasis is on science as a process rather than specifics of a particular field or topic. This series of courses fulfills their GE requirement for scientific inquiry, as well as their disciplinary writing requirement.

The disciplinary writing requirement is satisfied by courses where students learn to write within a specific discipline/field. In the year-long interdisciplinary program described above, students write short (5-6 page) papers in the first two quarters of the course, and also receive instruction on using the library and how to read scientific literature. The assignment in the first quarter is a literature review based around one of a list of primary scientific papers provided to the students. They must put the paper in the broader context of its field, understanding how it builds on prior knowledge and is in turn built upon. For the assignment in the second quarter, students chose from a provided list of scientific debates and used the skills learned in the previous quarter to research the debate and come to their own conclusion about the most supported viewpoint. With both papers, the assignment is scaffolded, with various parts due throughout the quarter and students are given feedback throughout the writing process. The bulk of writing expected to satisfy the requirement, though, is meant to be part of the third quarter seminar course.

2.2 Course Description

The course in question for this study is a seminar in the third and final quarter of the year-long program, focusing on astrobiology and science journalism. It is designed as a writing-intensive science course for non-STEM majors. Since this course fulfills science requirements, students with non-STEM majors typically enroll. Additionally, since this year-long experience is not a required program, there is a possibility that the program self-selects for particularly interested and motivated students, and students have some prior exposure to concepts about science from the first two quarters – to adjust for the latter, we compare pre- and post-course surveys to get a sense of the changes that happened over the duration of only the writing-intensive science course, as opposed to the whole year-long program. 11 out of 21 students from the 2021 offering of the course consented to the retroactive use of information from their course evaluations for this study, and 20 out of 21 students from the 2022 course responded to one or both of the assessments designed for this study. 5 students from those two course offerings agreed to interviews to discuss their experiences. Demographic information such as race and gender was not collected from participants, as it is outside the scope of this study.

In this writing-intensive science course, students worked through projects to develop a popular science article, from idea to pitch to full draft, on some topic related to astrobiology (e.g. planetary science, search for extraterrestrial intelligence (SETI), astronomy, space exploration). They had two major writing assignments: (1) a "translation" piece where they summarize a research article for a lay audience using the Astrobites format (Sanders et al., 2012, 2017; Khullar et al., 2019; Lewis et al., Prep) and (2) a more open-ended project that is scaffolded to take them from an initial idea to a fully developed article with an accompanying pitch for publication.

These major assignments were supported with smaller assignments to explore other multimedia forms of science communication (e.g. social media, podcasting, video), a weekly writing journal to practice science writing skills, and readings from science publications, both technical and non-technical. There were also in-class activities to build various writing skills, such as genre awareness, knowledge of audience, skill in word choice and structuring writing, and revision. Readings and discussions included mention of diverse practitioners of science, how to interview scientists for journalism, what science is and how it's done, and reflection on existing perceptions of science. The course met once a week for 2 hours and 50 minutes for 10 weeks, with approximately 9 hours of out-of-class work each week for a total of 12 hours.

2.3 Assessments and Data Collection

Surveys were administered in Weeks 0 and 1 (pre-course) and in Week 10 and Finals Week (post-course) to gauge student attitudes before and after the course, in the form of a Google Forms survey. The survey contained both Likert-scale quantitative questions and open-ended written response questions. Data from the Likert-scale questions are not included in this paper due to the small sample size. Student responses were not anonymous, but identifying information was only used to match pre- and post-survey responses. All protocols for this study were approved by UCLA's Institutional Review Board (IRB#22-000440).

The open-ended qualitative questions in the survey assessments are designed to gather nuanced information on student experiences and how they felt writing related to their changes in perspectives. Some of these questions were taken from Raved and Assaraf (2011), which provided a qualitative look at student attitudes in a 10th grade classroom via interviews. The written response open-ended questions were the same on the pre- and post-course surveys, and were as follows:

1. Are you interested in astronomy? Why or why not?
2. Why do you want to learn about science journalism?
3. How is the science you learn in school relevant to your daily life?
4. How do you benefit from learning about science in college?
5. How do you feel when reading scientific research articles?
6. How do you feel when reading about science in magazines, newspapers, etc.?
7. What does it take to be a good scientist?
8. How do you feel about explaining science concepts to others?
9. Do you think you could write about a new scientific discovery? Why or why not?
10. Is it important for scientists to have good writing skills? Why or why not? *(Note: this question is not used/analyzed in this work)*
11. What do you think of the way science is portrayed to the public? *(Note: this question is not used/analyzed in this work)*

We explored student responses to open-ended survey responses through the lens of reflexive thematic analysis (Clarke et al., 2015). Responses to Questions 1-9 were grouped by author BLL into various thematic categories (referred to herein as codes), described in their respective sections below. These codes were determined inductively; that is, they were not pre-determined, and were instead created based on the content of student responses. All responses were read once before creating codes, and responses were then re-read three times to refine upon the initial identification of themes/codes. As described in Clarke et al. (2015) and Yardley (2015b), we approach coding as a flexible, organic, and evolving process that cannot be fully separated from the perspective of the researcher, with no single "accurate" way to code data. Accordingly, we do not compute inter-coder reliability scores for this study.

Questions 1, 3, 4, 5, 6, 8, and 9 were also grouped into 5 categories based on their change from pre- to post-course responses using the same process described above. These categories are: positive change / improved, no change (positive), no change (neutral), no change (negative), and negative change / decreased as described in Table 1. Positive change is defined as moving towards the desired outcome (e.g. increased interest in STEM, increased confidence and sense of ability in STEM, more diverse and open views of science and scientists). The three categories of "no change" indicate that student views have either remained positive, remained neutral, or remained negative. Student responses, particularly long quotes or those presenting multiple ideas, may be coded as multiple emergent themes, but each student responses is only counted in one of the change categories (e.g. an answer cannot count for both "yes" and "no"). Not all students replied to all questions, and so the number of informative responses for each question varies; the total number of students, including those who skipped a question, is N=20. Additionally, some students provided responses that were illogical or otherwise unable to be matched to a code; the number of these uncoded responses is also provided for each question. Selected student responses are provided in quotations to illustrate participants' thoughts, in their own words; these are labeled with the corresponding code this survey response was labeled as. To visualize the results of the coding of student responses with respect to change in attitudes, we created a summary bar chart (Figure 1).

The post-course survey included an option for students to be contacted for interviews about their experiences to gather further qualitative data. Five students agreed to and completed interviews. Student quotes from interviews and open-ended questions are reported in Section 3. Interview quotes were not coded, as the content of those questions varied significantly from that of the survey, and relevant selections are instead included in Section 3.4. The interview questions were as follows:

- How has writing about science impacted your experience with learning about science?
- What do you feel is the most important lesson you've taken away from this course?
- Which of your views about science has changed the most while taking this course?
- How do you feel about engaging with science beyond this course?

Although this investigation had not yet been designed during the first offering of this course in Spring 2021, we did collect some pre- and post- course survey data as well as qualitative feedback from students about their attitudes towards writing and science and their experiences in the course. Students were asked for consent to use their responses to explore if there were any valuable insights that may be useful to this study. All student responses are from the 2022 study, unless otherwise noted as information pulled from the 2021 course evaluations.

2.4 Limitations

As mentioned in the introduction, the scope of this work is limited by its nature as a case study. This work focuses on a small, specific and unique population of students, who have some overlap with a typical lower-division introductory astronomy course but are not quite the same due to the nature of the course. Accordingly, as a case study, we take a deep dive into student responses, including claims by even single students; we consider all student responses valuable, whether or not they are repeated by other participants, and identify recurring themes among student responses. Additionally, the survey did not directly probe student ability, instead asking students for their *perception* of their abilities. Although students may have felt more confident, it is important to note that we do not have data to support change in their actual abilities or skills.

3 Analyses & Results

A summary of changes in student attitudes based on responses to open-ended survey questions is presented in Figure 1. Results in this chart will be further discussed in the following subsections in five main categories: interest in astronomy, perceptions of benefits and relevance of science, perceptions of ability in science,

Question	Definition of Positive Change	Definition of Negative Change
Q1: Interest in Astronomy	Student answer changes from “no” to “yes” or provides a more detailed / enthusiastic response. Example: “Yes because I was always fascinated about planets and stars.” → “I am interested in astronomy because space has always been interesting to me. The planets, the stars, the rockets, it always made me wonder about things out of this world. Plus…”	Student answer changes from “yes” to “no.” Less detail is classified as neutral, as long as the overall attitude is still that science is interesting. Example: “I am interested in learning about the processes beyond our planet, especially considering astrobiology.” → “No. It is not a career/ hobby I see myself pursuing. I am more into humanities/politics.”
Q3: Relevance of Science	Student identifies more examples of why science is relevant or shows deepened appreciation for the relevance of science. Example: “Doesn’t impact it career-wise but I find it really interesting” → “Most of it isn’t applicable to daily life. However, learning how to think with the scientific process is important.”	Student answer changes from “yes” to “no.” Less detail is classified as neutral, as long as the overall attitude is still that science is relevant. Example: N/A
Q4: Benefits of Learning Science	Student identifies more examples of why science is beneficial or shows deepened appreciation for the benefits of science. Example: “I’m not a STEM major, so for me it’s more advancing my understanding when reading scientific journalism and learning about interesting facts.” → “It’s always beneficial to continue learning about science. College continues that well rounded education if I’m learning about science, even if I’m not a science major.”	Student answer changes from “yes” to “no.” Less detail is classified as neutral, as long as the overall attitude is still that science is beneficial. Example: N/A
Q5: Perception of ability [reading research articles]	Student response displays greater confidence (e.g. stronger/more enthusiastic language). Example: “Usually I do not understand much” → “I used to feel overwhelmed but now I see it as a challenge and something exciting to learn about”	Student response displays lower confidence (e.g. weaker/less enthusiastic language). Example: N/A
Q6: Perception of ability [reading science news]	Student response displays greater confidence (e.g. stronger/more enthusiastic language). Example: “Sometimes very interested, sometimes not so; depends on the scientific topic” → “Good as it is engaging and interesting”	Student response displays lower confidence (e.g. weaker/less enthusiastic language). Example: N/A
Q8: Perception of ability [writing about science]	Student response displays greater confidence (e.g. stronger/more enthusiastic language). Example: “Maybe. I do not want to say "no" since I have not really done this…” → “Yes! With enough time, I think I can understand and write about a new scientific discovery.”	Student response displays lower confidence (e.g. weaker/less enthusiastic language). Example: N/A
Q9: Confidence in explaining science concepts	Student response displays greater confidence (e.g. stronger/more enthusiastic language). Example: “Usually I can’t because I don’t understand them on a deep enough level” → “After taking this class I feel like, if I put enough time and work into understanding the concept myself, I could find a way to explain it clearly to others.”	Student response displays lower confidence (e.g. weaker/less enthusiastic language). Example: N/A

Table 1. Definition of “positive” versus “negative” change for each question coded based on matched pre- and post-course responses.

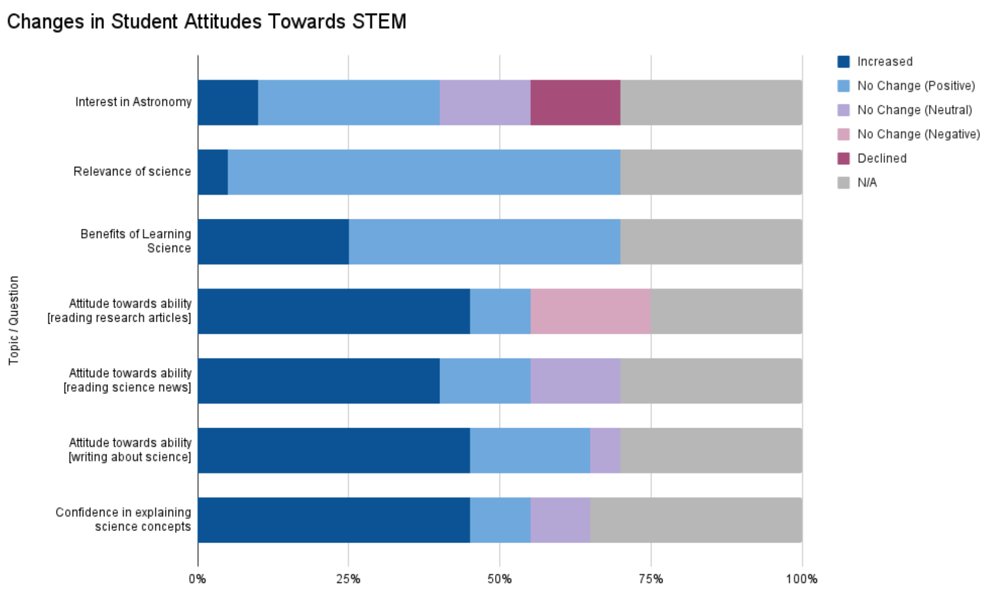

Figure 1. Bar chart illustrating changes in student responses from before and after the courses, for a sample of N=13-15 students depending on the question. Dark blue indicates an improvement from students’ starting opinions, and dark pink represents a more negative opinion (with negative and positive defined as in Table 1). The three lighter colors – light blue, light purple, and light pink – represent no change from the initial opinion, where students’ opinions remained positive, neutral, or negative respectively. Grey indicates the student did not respond to both surveys, and therefore change in attitude cannot be measured. Students display little change in their interest in astronomy and perceptions of the relevance and benefits of science, but increases in their perceptions of their own ability to engage with science, and their confidence in explaining science concepts.

Response Category	Response Code	N (before, 20)	N (after, 20)
Yes, because...	...I am **curious** about the universe, it's **fun** to think about, or I think planets/stars/space are **cool**.	14	14
	..it's important to **understand things happening on Earth**.	1	0
No, because...	...it's not what I see myself doing for a **career**.	1	6
	...I prefer **social / humanities** issues and topics.	1	1
	...it **doesn't affect me** in any way / isn't **relevant** to my daily life.	1	1
	...it feels too **abstract**.	1	1
No response	N/A	4	2

Table 2. Student responses to the question "Are you interested in astronomy? Why or why not?" coded by the theme of their response. Students came in interested, and stayed interested, but confirmed their career choices in other fields.

Response Code	N (before, 20)	N (after, 20)
I am motivated to **improve my writing skills in general.**	4	5
I want to **get better at writing and reading about science** in particular.	10	5
I think it's **important to portray science to the public** in an understandable / engaging way and/or **understand how science is disseminated.**	1	8
I **don't** have any particular interest in this.	1	0
No response	4	2

Table 3. Student responses to the question "Why are you interested in learning about science journalism?" coded by the theme of their response. Interest level seems similar between before/after, but comments became more specific (e.g. mentioned things like jargon, audience, difference between research and public articles).

perceptions of scientists, and other insights from interviews with student participants.

3.1 Interest in Astronomy

Student interest shows a small positive change, and is the only metric to show a decrease in some students, as shown in Figure 1. 9/20 (45%) showed no change, either coming in with an interest in astronomy and maintaining that interest, or coming in neutral and remaining neutral. Narrative responses investigating student interest in astronomy were coded into two main positive and four negative categories, displayed in Table 2. A majority of students (14/20, 70%) explained that their interest stemmed from a curiosity or sense of entertainment when thinking about their place in the Universe.

Another question on the survey probed their interest in this course's other main topic – science journalism – upon entry to gauge reasons for taking the course. Students replied in three main categories: a desire to improve their general writing skills, a desire to improve their discipline-specific (e.g. science) writing skills, and a belief in the importance of communicating science to the public, summarized in Table 3.

The following are examples of student responses conveying these sentiments, with their corresponding codes:

> *"It is interesting to see how different parts of life work, and that includes journalism. It is cool to feel like you are on the writing side for once when for the rest of your life, you are the one reading articles." [Code: Understanding portrayals/dissemination of science]*

> *"I want to learn about science journalism because it is important to understand how the science that we read about in publication is released to the public." [Code: Understanding portrayals/dissemination of science]*

> *"Science is important to understand even if it is not something you want to do with your life." [From 2021 Evaluations]*

> *"Science is so cool and even though I might not understand all of the physics/math/computer coding, appreciating the topics conceptually is so important and I want to continue to stay informed." [From 2021 Evaluations]*

3.2 Perceptions of Benefits and Relevance of Science, and Scientists Themselves

Student responses regarding the benefits of science were coded into the following categories, listed in Table 4: science broadens their perspective on the world, helps them understand the world, improves critical thinking skills, helps them be informed on current events, provides additional career options, and helps them become a better advocate for science. Only one student explicitly said that science did not benefit them, and this student did not fill out the post-course survey so it is unknown if the course changed their view.

Student responses to the question regarding relevance were coded into 5 main emergent categories, which in turn coincidentally parallel the categories of "relevance for understanding scientific phenomena" and "relevance for being an effective citizen" from Stuckey et al. (2013). These categories of student responses, shown in Table 5, are science is relevant for: understanding and appreciating the world, critically approaching news, understanding the scientific process, becoming informed on climate change, being informed on personal health, and not relevant. Note: the latter two categories parallel some of the largest science-related events in the news at the time of this study: the climate crisis, and the COVID-19 pandemic.

Students in this course identified many of the expected positive qualities of a scientist – hard-working, dedicated, curious, open-minded, passionate – in both the pre- and post-course surveys, as visualized in Table 6. Only 2/20 students (10%) responded with stereotypes requiring innate talent or solitary brilliance in the pre-course survey, and even then they mentioned it with a caveat (e.g. innate talent can help but hard work is needed).Additionally, there was a noticeable addition of mentions of ethics, morals, and communication to the required skills of a good scientist after the writing-focused science course: four additional responses regarding morals, communication, or empathy in the post-course survey. One student left a particularly illustrative response on this point:

> *"My whole life I was told it was objectivity. Now I would disagree with that though. Science isn't objective, it is widespread, pervasive, and extremely personal. It is our future and our money. So, the most important qualities in science are being a good communicator and being ethical." [Codes: good communicator, morals / ethics / integrity]*

3.3 Perceptions of Ability in Science

We asked students about their feelings towards four tasks related to science: reading scientific research papers, reading popular science writing (e.g. magazines, news), explaining science concepts to others, and writing about a new scientific discovery. As shown in Figure 1, over 25% of students showed an increase in all four metrics of student ability (e.g. the four tasks we asked them

Response Code	N (before, 20)	N (after, 20)
I benefit from a **broadened perspective** on the world.	1	3
It helps me **understand the world** around me.	7	8
It improves my **critical thinking skills** by learning about the process of science.	4	6
It helps me be **informed on current events** / political debates.	2	0
It opens up additional **career options.**	2	2
It helps me **become a better communicato**r and advocate for science.	1	1
It **does not** benefit me.	1	0
No response	5	4

Table 4. Student responses to the question "How do you benefit from learning about science in school?" coded by the theme of their response. Students had strong reasons for why science is relevant to their lives.

Response Code	N (before, 20)	N (after, 20)
Learning about science in school helps me **understand and appreciate the world** around me.	9	6
Learning about science **helps me understand news** and current events.	2	5
Learning about science teaches me the **scientific process and research skills**.	1	1
Learning about science makes me more informed on **climate change**.	2	4
Learning about science makes me more informed about my **personal health.**	2	2
Learning about science is **not relevant** to me.	0	1
No response	6	3

Table 5. Student responses to the question "How is the science you learn in school relevant to your daily life?" coded by the theme of their response.

Response Code	N (before, 20)	N (after, 20)
A good scientist is **curious**.	5	6
A good scientist is **attentive/detailed**.	2	1
A good scientist has **knowledge** about their field.	1	3
A good scientist follows the **scientific process**.	2	3
A good scientist is **committed / dedicated / patient** and **perseveres** through failure or hardship.	8	8
A good scientist has **morals / ethics / integrity**.	2	3
A good scientist will **work hard**.	5	6
A good scientist is **passionate** about their work.	3	1
A good scientist is **open-minded** and tries to be **unbiased**.	3	1
A good scientist is a **critical thinke**r.	2	0
Some good scientists have **innate talent**.	2	1
A good scientist has **experience**.	2	0
A good scientist **reads a lot** to keep up with discoveries.	0	1
A good scientist is a **good communicator**.	0	2
A good scientist is **empathetic**.	0	1
A good scientist is **creative**.	0	1
No response	3	2

Table 6. Coded student responses to the question "What does it take to be a good scientist?" Students list standard positive qualities with no strong notice of change before/after. There is a noticeable addition of mentions of ethics, morals, and communication to the required skills of a scientist post-course.

about) to engage with STEM after participation in the course.

In the pre-course survey, 16 out of 20 students (80%) reported some form of negative feeling towards reading primary scientific research literature (e.g. codes "too complicated", "overwhelmed", "confused"). In the post-course survey, 9 out of 20 students (45%) report these negative feelings. Eight students (40%) report feeling "better" "comfortable" and even "confident" in reading research papers post-course, with some even claiming to "enjoy" the challenge, while at the same time acknowledging that this is a difficult task. For example, see the following quotes from student responses:

> *"I used to be very intimidated by the jargon and the non-engaging writing style, but now I feel comfortable at least skimming those articles." [Code: comfortable]*

> *"I used to feel overwhelmed but now I see it as a challenge and something exciting to learn about." [Codes: challenging, excited]*

Over half of students who responded to the question (8/14, 57%) report increased positive attitudes towards reading these types of articles, describing them as "cool" and "interesting" and saying they "enjoyed" them, as shown in Table 8, and such as in this student response:

> *"[I feel] much better than when I read scientific research. This material is accessible while educational, enabling someone without a professional background to understand the science involved. I feel like there's actually a point to reading it." [Codes: better than technical sources, purposeful, can understand]*

We also probed student abilities to *actively* engage with science, such as through explaining scientific concepts to others. The number of "confident" students increased from 1 to 4 (5% to 20%) across the course and the number of students who report an inability or discomfort with the task dropped from 4 to 0 (20% to 0%), as shown in Table 9. Students also mentioned that practicing explanations helped them improve their own understanding, such as in the following responses:

> *"I think to be able to explain science concepts to others is a way to prove that you actually understand the concept yourself." [Code: N/A]*

> *"After taking this class I feel like, if I put enough time and work into understanding the concept myself, I could find a way to explain it clearly to others." [Code: can do it]*

Lastly, we gauged student attitudes towards writing about science before and after the course. Responses showed a positive trend, as shown in Table 10. Before the course, 11 students (55%) reported they maybe or could complete the task, 2 (5%) were unsure, and 4 (20%) reported they could not. (Note: Percentages generally do not add up to 100%, as some students did not respond to each question.) After the course, 15 students (75%) reported they maybe or could, while 3 (15%) were unsure and only 1 (5%) reported they could not. Pre-course, students also hedged with words and phrases like "maybe" and "with help" or "with a good editor" or "with enough time." Post-course, students showed more confidence, but still wanted more practice and time to hone their skills. There is some evidence of additional understanding of different modes/audiences of scientific writing, and some students said their confidence level depended on the audience or topic. One student response captures the transition from pre- to post- course attitudes and the value of a course focusing on science writing and communication:

> *"I think that, after taking this class, I could write about a new scientific discovery because I have been taught the process and worked through it with someone who has practice." [Code: can do it]*

3.4 Commentary from Interviews

In this section, we present selected relevant quotes from student responses, themes and summary information from student interviews, and context from the interviewer. Five students were interviewed, and the selected quotes presented here were chosen to illustrate the unique sentiments conveyed by the participants.

How did writing about science impact your experience learning about science?

> *"I think by having to relay the information in an accessible, clear manner, you have to really understand it... Like you have to understand it well, in order to explain it to different groups of people. So I think it just forced me to have a firm grasp of it, in order to be able to like, explain it clearly."*

> *"With science, you really have to know what you're talking about. So if you weren't sure about something, it kind of inspires you to go research, go back and check."*

> *"It really did. Because a lot of times science and STEM stuff feel super divorced from humanities. Which, if you're a humanities major, or just have humanities interests, like, oh, well, I guess this isn't really meant for me. But like, this is kind of marrying it. I love synthesis. And so this synthesis of like, the sort of critical thinking that you have to use in like, an English major, and kind of applying that to science is the best of both worlds for me."*

> *"Writing helped me really think about it from my perspective... when I was writing about it, I was able to actually think about my opinion on it. And, like, really get deep into it. So helped me like, synthesize what I learned, and form my view of the topic."*

A majority (4/5, 80%) of student interviewees reported during interviews that the process of teaching material through their own written explanations increased their comprehension of the material, and the requirements to write and explain the material helped them to reiterate and remember the information in a way that they claim hadn't been present in their other STEM-related courses. One student found that writing about science made the learning more "manageable" and two others who had previously not enjoyed learning about science in the more "traditional" ways (e.g. from textbooks and lectures) found this method of active, project-based, writing-focused learning more interesting and engaging. One student, quoted above, explained that incorporating writing into science education helped make science feel more relevant and related to their experiences and interests in the humanities, providing them with an entry point into the material based on their prior experiences – more discussion on this in Section 4.5. Another student explained that writing about science forced them to consider their perspectives on debates and current events in science, and to dive deep into the topic at hand.

"What was your biggest takeaway from the course?"

> *"We need to spread the word that scientists and like everybody needs to know how to write... the biggest thing I learned is probably that it's super important for the [science] writing to be accessible. That's what's gonna make people not be scared of the truth and the facts, is like if they can kind of understand it a little bit more."*

> *"The most important lesson is that I think things seem scary before you try it. Because all scientific writing, as I said before, was really intimidating. And it was just academic and boring for me. But after I, like, tried it, I mean, we had to kind of try it with their writing journals and stuff, after we started writing more often helped me realize that, like, things may seem scary at first, but when you try them, it's like, you'll get used to it and might not be as hard as you think it is."*

> *"I think that a lot of classes should integrate more writing as part of*

Response Code	N (before, 20)	N (after, 20)
I am **interested** in the articles.	2	1
I am **curious/inspired** to learn more.	2	1
I am **excited** to read them.	1	1
I **enjoy** reading them.	0	1
I am **comfortable** reading them and can **understand** the content.	0	3
I feel **confident** reading them.	0	2
I feel **better** than I did before the course.	0	2
I feel **informed** or find them **useful/rewarding.**	3	0
I feel **calm/neutral.**	1	1
Reading these articles **takes me a lot of time** / they are **too complicated.**	3	0
I want to **get it over with.**	1	0
I feel **overwhelmed** and/or **stressed.**	4	3
I feel **bored** / the articles are **uninteresting or dry.**	3	2
I find reading them **tedious.**	1	0
I feel **confused/lost** or **do not understand.**	3	1
I find reading them **challenging or difficult.**	1	3
I find reading them **exhausting.**	0	1
I feel **intimidated** reading them.	0	2
No response	4	2

Table 7. Student responses to the question "How do you feel when reading scientific research articles?" coded by the theme of their response. There was a clear improvement in student comfort with reading primary research articles.

Response Code	N (before, 20)	N (after, 20)
I **enjoy, love, or have fun** reading these.	2	5
I **can understand** the concepts within these articles.	4	2
I feel **confident** reading these articles.	1	1
I find these articles **interesting, exciting, engaging, or entertaining**.	8	6
I feel like these articles are **relevant / purposeful**.	1	1
I feel **informed / curious** reading these articles.	0	2
I feel **better now** than I did before the course.	0	1
I think these are **better than technical sources**.	0	1
I am **neutral / don't dislike** reading these.	0	2
I am **skeptical** of these articles or **worried about their reliability**.	4	1
I feel **confused** while reading these.	0	1
I feel **bored** while reading these.	1	0
No response	4	2

Table 8. Student responses to the question "How do you feel when reading about science in magazines, newspapers, etc.?" coded by the theme of their response. No students like reading about science less than when they started. Responses also illustrated a greater understanding of genre, and the distinguishing features (namely audience) between research papers and popular science writing. Overall more positive attitudes both before and after than towards primary research articles.

Response Code	N (before, 20)	N (after, 20)
I **love / enjoy / have fun** explaining science to others.	3	1
I am **comfortable** explaining science to others.	3	3
I am **confident** in explaining science to others.	1	4
I **can do it** if I put in the work.	0	2
I feel **better** about it than I did before the course.	0	1
I have **mixed feelings** about explaining science / it **depends on the subject**.	5	6
I am **not confident** / **not comfortable** explaining science to others.	3	0
I **can not** explain science concepts to others.	1	0
No response	4	2

Table 9. Student responses to the question "How do you feel about explaining science concepts to others?" coded by theme of their response. The language students used in response to this question changed from comfortable (with mentions of worries of being incorrect), to a mostly confident.

Response Code	N (before, 20)	N (after, 20)
I believe **I can do it**.	4	11
I could **maybe** do it, **depending on the topic**.	1	1
I could **maybe** do it, **given enough time, guidance, and editing**.	5	2
I could **maybe** do it, but would **rather do something else**.	1	1
I am **not sure** if I could do it.	2	3
I **can't do it** now, but **would like to try** in the future.	1	0
I **couldn't do it**, since I **couldn't understand the science**.	2	1
I **couldn't do it**, since I am **not a strong enough writer**.	1	0
No response	4	2

Table 10. Student responses to the question "Do you think you could write about a new scientific discovery? Why or why not?" coded by the theme of their response. There is some evidence of additional understanding of different modes/audiences of scientific writing, and some students said their confidence level depended on the audience.

like a science education…And I think I really would have benefited from that, just because that's part of the way that I learn."

Two students' major takeaways from the course related to the elements of writing – audience, style, structure, sentence-level concerns, etc. – and their ability to connect different pieces of evidence into a coherent story, which is somewhat expected given that this course fulfilled one of the students' major writing requirements. Two other students mentioned takeaways about the science content, such as the idea that science is interesting and their perspectives on life in the universe have changed (understandable again, given that this is a course focused on astrobiology and aliens.) Four students (since some had multiple answers to this question) also mentioned takeaways that related more to perceptions of science and the role of communication in STEM, such as the fact that they now see writing as an important skill, even for scientists, and the idea that better science writing will lead to better science literacy in our society. One also mentioned metacognitive takeaways, such as the idea that trying new things and pushing yourself is important for learning, as cited in the second quote of this section. One student even directly identified writing as a key part of what made their learning successful in this course, claiming that more courses should integrate writing (as in the last quote above) and pinpointing that active learning activities like the writing in this course led to a better learning experience for them. We will discuss the idea of writing as active and experiential learning for science further in Section 4.4.

"Which of your views about science changed most during the course?"

"Probably the idea that it can be a creative endeavor as well…like, the scientific method, it seems very structured. And while I love structure, it's like…if you structure it too much, then that can feel confining."

"There are people who like…take articles and information and just make it accessible to people…There are people who are trying not to make it [science] as gate kept."

"Scientists need to communicate, because all of them are doing different things, and it's very naive to believe that they're all on top of each other's work all the time, even though that's kind of the impression you get from not being in that field."

"This course did not change how I perceive science necessarily – I still see it as very much a system of like the scientific method, peer review, all those things that have been ingrained in me since like, fifth grade. But it's changed kind of how I view science within the larger like, educational and media landscape."

A majority (4/5, 80%) of student interviewees also report having changed their views of science itself and how it works in some way – even the student whose quote above begins to say that his perception "did not change" but then later cites a change in his previous view of science as a centralized "institution," now understanding that science is more of a collaborative collection of people working independently but cooperatively. Another, quoted above, mentions their expanded view of *who* participates in science and how – they were previously unaware of writing and outreach roles in science, jobs beyond the stereotypical scientist role, which they were excited to learn existed to make the field more accessible to people like themselves. This student described this expanded view as helping them move away from the idea that science is "stuffy" or "elitist." One student expressed a distaste with the idea of science as rigid, and a realization that there was a connection between the creativity they sensed in their own humanities and artistic studies and real science. Additionally, one student expressed an appreciation that the skills they learn in humanities courses (e.g. writing, communication) actually *are* relevant and transferrable to science, helping to bridge the often daunting gap between the two fields (discussed further in Section 4.5). One student also mentioned was that this course changed their view on whether or not life exists beyond Earth – an interesting outcome, and somewhat expected for an astrobiology course, but not particularly relevant to this investigation.

"How do you now feel about engaging with science, and has that changed since the beginning of the course?"

"I can approach it [science] with more understanding, like if I'm reading an article or something, or like listening to a new story about whatever. I feel like I can grasp the full picture. Like when they launched the telescope [JWST], I feel like I understand like, okay, like, this is what it's like trying to achieve and do, even if they don't say that explicitly."

"I knew going into college, I didn't want to like be in STEM, I didn't want to necessarily be practicing science. But that doesn't mean that I can't like engage with it. So that's kind of like my big takeaway. Like, I could still for fun, like write science articles online if I wanted to, or just things like that. I didn't really ever think about that [before]."

In the interviews, students also shared some concrete ways in which they are taking steps to engage more with science in their lives. One student decided to take some climate change courses as part of their undergraduate education, and one is considering adding a science minor after their experiences in this course. Another student, involved in a journalism group on campus, mentioned that they now have more confidence to take on journalism assignments related to science, whereas before this course they would pass on science-related assignments offered by their editors. One student also explicitly mentioned that this course and the science writing instruction within helped them know what to look for in science news, providing them with both reading skills and science content to help determine if an article is reliable or worth their time to read.

"Is there anything else about how this course impacted you that you'd like to share?"

> *"Your course just kind of broadened even more like the idea that anybody can be a scientist, you just have to kind of try at it and be curious. And like anybody can learn things. Definitely it's helped me move on to be a little less nervous about jumping into things that I'm not entirely sure about, like, scientifically."*
>
> *"I can write about science for the rest of my life without even having to formulate my own experiments/do research! (Not that I have anything against research, I was just surprised by how accessible the process of science writing actually is.)." [From 2021 Evaluations]*

Space was given to students to mention anything else relevant to their course experience. Two student interviewees and a majority of responses from the 2021 evaluations commmented on facets of the course, such as their thoughts on the course instructor, which were not relevant to this investigation – however, there were two relevant and interesting responses from students, which are quoted above.

4 Discussion

Student feedback and responses from this investigation revealed a number of interesting takeaways for both *how* and *why* science writing education was impactful for their learning and views surrounding STEM. In this section, we discuss interpretations of the coded survey response data and interviews, then present our takeaways from this case study: two major themes of how we believe this learning experience affected their views, and two major themes of why we believe science writing was a useful tool for learning about astronomy / science.

4.1 Interpretation of Survey Responses

Interest in Astronomy

Interest is the only metric in our investigation that shows a decline. Most of the decreases in claims of interest seem to stem from responses that students are not interested because it's not what they see as their career – indicating that students may have interpreted the question somewhat differently than intended, as if "interest" requires a commitment to career on the topic. As mentioned in Section 2, this student population likely had high interest coming in, due to the self-selecting nature of this course and their previous exposure to the topic in the earlier parts of the year-long program.

Perceptions of Science: Benefits, Relevance, and Scientists Themselves

A majority of Americans currently think science is mostly beneficial to society, and perceptions of science as beneficial scale positively with science education level (Pew Research Center and Funk, 2020). Somewhat unsurprisingly, students in our study nearly unanimously agreed that there was *some* benefit to learning about science in college, either entering with positive views and remaining positive, or entering neutral and becoming more positive. (The benefits of science are emphasized in the first two quarters of the year-long program this course is a part of.) Similar to perceptions of the benefits of science, students already appreciate the relevance of science before the course, but added some nuance or detail to their responses after the course.

Students additionally entered with fairly well-rounded perceptions of the traits needed to become a scientist. This is again unsurprising, as these are features of scientists that are explored in the first two quarters of the year-long program. In this seminar course, students were also able to make a direct connection to their instructor, an early career, female, first-generation astronomer, and the course featured representation from and discussion of other diverse scientists and writers, which may have had an impact. Additionally, awareness of negative stereotypes of scientists has existed for years (Losh, 2010), and it appears that the many mitigation strategies in place (e.g. outreach programs such as Skype a Scientist and pedagogy initiatives such as Steinke (1997); Thomas et al. (2006); Yardley (2015a); Jarreau et al. (2019)) are making a difference. However, students did notably include traits like morality, communication skills, and empathy in the post-course survey, as well as in interviews–this is further discussed in Section 4.

Perception of Abilities in STEM

Although students came in with positive perceptions of the importance of science as a field and well-rounded views of the skills needed to be an effective scientist, these beliefs did not appear to extend to themselves. Many students entered hesitant about their abilities to learn, write, and discuss about science topics.

Students overwhelmingly began the course with negative attitudes towards the prospect of reading scientific technical writing, with "overwhelmed" being the most used word in their responses, as illustrated in Table 7, while acknowledging that there may be interesting content hidden within. Although students were exposed to primary scientific literature in the other portions of the year-long program, those experiences do not seem to have made them feel more prepared for engaging with technical scientific writing – it would be interesting in future work to determine if this prior experience changed student attitudes, determining if more typical (e.g. not self-selected as described in Section 2) non-STEM majors in a GE course hold the same beliefs. This metric shows a positive change after the course, wherein students experienced directed reading assignments, guidance on how to tackle research articles, and assignments where they translated the big ideas of the articles for a more general audience.

In their daily lives, students are more likely to encounter secondary sources of science news, such as popular science articles in magazines. Unsurprisingly, given that students are the target audience of these types of publications unlike primary research articles, incoming attitudes about reading popular science articles were much more positive. However, post-course responses also illustrated a greater understanding of genre, and the distinguishing features (namely audience) between research papers and popular science writing. Students seemed to understand that these articles were *meant* for them, and indicated appreciation for the form. Critical reading and understanding genres are relevant skills to take away from an introductory science course, and can empower them to be scientifically literate and involved citizens.

Writing, arguably the most active and involved task related to engaging with science in this study, requires students to synthesize many of the prior skills: reading and understanding primary sources, understanding the style, audience, and purpose of popular science writing, and explaining science concepts to a lay audience (Hamdan*, 2005; Hobson, 1996). This task, too, showed an increase in positive attitudes, with nearly half of respondents reporting an increased confidence in writing about science.

4.2 How: Expanded Views and Increased Confidence in Ability for Engagement with Science

Takeaway # 1: Writing-focused science education expands how our participants think of engaging with science, providing new pathways beyond careers for them to be involved in STEM, and greatly increases their confidence in their own ability to engage with STEM in various ways.

In the student responses displayed above in Section 3, students showed increased confidence in their abilities in a variety of tasks, covering a range of cognitive processes and domains of knowledge (Bloom et al., 1956; Krathwohl, 2002; Anderson and Krathwohl, 2001), related to engagement with science content:

- **Remember**, **Understand**, and **Evaluate**: Critically reading articles about science, for both general and technical audiences
- **Remember**, **Understand**, and **Apply**: Explain science concepts to others
- **Understand**, **Analyze**, and **Create**: Write about a new scientific discovery

Additionally, students **in this course**, both in survey responses and interviews, demonstrated a broader understanding of how people can be involved with science – an expansion of students' prior conception that only active researchers, who pursue STEM as a career, can engage meaningfully with scientific knowledge. Often, the conceptualization of what it means to be "involved" with science is limited to those who are active practitioners within professionalized scientific careers (that is, those practicing science as their main job), and students are aware of few in-roads to further engagement with science beyond science as a profession (Avraamidou and Schwartz, 2021). The quotes in Section 3.4 illustrate that this course, including exposure to science writing and more explicit discussions about how science works, may have been able to broaden student knowledge and awareness of varying levels of engagement with STEM (e.g. as a career, citizen science projects, amateur astronomy, writing and journalism, consuming news) that are available as valid options in their lives. Students in our sample after this course seem to see engagement with science, from the citizen/non-professional point-of-view, as a meaningful part of science – an attitude that science communication and citizen science efforts try to foster (Bonney et al., 2016; Williams, 2000; Azevedo and Mann, 2018; Ibrahim, 2015).

Determinations of the level of the change in student engagement (e.g. no interest vs. appreciation of news, passing interest vs. career) are currently limited by the data collected, but could be probed in future work. It will be important to consider what our goals are for students' engagement levels, since we can not (and should not) aim to convert everyone to a STEM major or career; it is also worth articulating exactly what we hope to gain with increased engagement, and this should be considered in future discussions and investigations.

4.3 How: The Roles of Ethics, Communication, Individuals, and Opinion in Science

Takeaway # 2: Writing-focused science education prepared our student participants to deal with science in a real-world context by emphasizing important "soft" skills used both in research and research-adjacent outreach work. By discussing ethics, effective communication, and the agency available to individual scientists, students in our course gained a more comprehensive understanding of work in and around science and develop new ideas about the skills and norms of an ideal scientist.

In this course, students were exposed to a variety of careers related to science beyond the pure research scientist jobs they are used to seeing represented (e.g. teaching, outreach, writing, policy, etc.). Within the scientific community, communication is increasingly well-established as a critical skill for scientists (Fleming, 2009), but even in studies of student perceptions of STEM jobs, these roles are not taken into consideration (Christensen et al., 2014). After this course, students in the course reported an expanded view of the different skillsets and roles it takes to make "science" happen, and they noticed the importance of communication – both within scientific communities and between scientists and the general public. Another interesting observation by a student was that they no longer saw science as a monolithic institution, but instead understood that there are individual people at work – all with their own opinions and even goals – working collaboratively.

As stated in Section 3, multiple students listed empathy, ethics or communication as traits of science/scientists after the class, but not before – this is an interesting change, and additional evidence of students in the course building their understanding of science in context and recognizing that science is political (Brown and Malone, 2004; Ball, 2021). For students to be able to critically approach science as it appears in their lives and become active and informed citizens, they must gain a greater understanding of the human elements of science, including ethics, politics, and science communication (Backhaus, 2019; Hodson, 2003; Elgin, 2011; Feinstein et al., 2013). Some programs are already incorporating this sort of discussion explicitly in Science-Technology-Society (STS) programs (Han and Jeong, 2014), such as the Human Biology and Society undergraduate major at UCLA (UCLA, 2022) and the Science Technology and Society Studies graduate certificate at the University of Washington (UW, 2022), but this investigation shows that science-writing-focused pedagogy can provide a platform for exploring these topics through discussion. Discussions of the role of science communication in science and public discourse in this course were provoked by lessons on audience (who we're writing for in different genres, e.g. research papers vs. magazine articles), whereas conversations on ethics (for science journalists, scientists, and other stakeholders) and politics came about when reading recent science news articles critically as examples of good writing.

4.4 Why: Science Writing as Active and Experiential Learning

Takeaway # 3: Writing-focused science education enhances learning because it is active and experiential, immersing students in a real-world task and requiring significant and meaningful engagement.

Active learning strategies – wherein students must actively engage in tasks related to their learning, instead of passively receiving information – have been repeatedly proven to be beneficial to student learning and concept mastery (Ritchhart et al., 2011; Zayapragassarazan and Kumar, 2012; Chickering and Gamson, 1987; Prince, 2004). Writing is an active form of learning, requiring research skills, synthesis, and self-directed inquiry (Hamdan*, 2005), and writing exercises have been shown to be an effective strategy for active learning (Linton et al., 2014; Butler et al., 2001). Similarly, peer learning has been demonstrated as an effective tool for increasing student learning (Hamilton-Hinch et al., 2021), and writing-to-learn is an established strategy in writing pedagogy (Ackerman, 1993; Rivard, 1994; Bangert-Drowns et al., 2004). The use of writing, both in writing-to-learn activities and more polished journalism activities, in this course seems to have positively affected student learning of the content as well. Multiple interview participants even directly acknowledged that writing forced them to deepen their understanding of course content.

Additionally, journalism / science writing assignments are relevant, real-world tasks that connect to aspirational goals (e.g. publishing an article) beyond the course; real-world assignments and incorporating recent discoveries are both effective strategies for increasing student engagement in the classroom (Nieves, 2020; Eales and Laksana, 2016; Laware and Walters, 2004; Wollschleger, 2019). Reading news articles critically is also a real-world task, one that we hope students carry through their lives – this is the crux of science literacy, and especially by talking about current events, they know that their classwork is relevant.

4.5 Why: Science Writing as a “Relatable” Entryway for Humanities Students

Takeaway # 4: Writing-focused science education enhances learning because it relates otherwise seemingly irrelevant/unapproachable material to the primary work of a non-STEM major / someone who does not wish to pursue a career in science.

There are a number of well-known challenges in introductory STEM courses. One of these challenges is that humanities students sometimes see science as just fulfilling a requirement, and are therefore not that invested. Increasing student buy-in (Cavanagh et al., 2016; Wang et al., 2021) and demonstrating the relevance (Stuckey et al., 2013; Newton, 1988; Frymier and Shulman, 1995) of the content are key issues in motivating students in class. Student participant comments on their perceptions of the relevance of science to their lives are discussed earlier in Section 3.2, but relevance of *course content* is a different issue than their absolute interpretation of the relevance of science. Even science content, otherwise possibly irrelevant to their lives, can be made relevant with effective teaching techniques, such as incorporating current events and research. This investigation shows that science-related writing instruction may be another avenue to increase relevance; students in the course report feeling that they are still gaining valuable skills in reading, writing, and critically interpreting science-related current events, even if they are learning content that is not directly related to their careers or aspirations.

Additionally, since science is often framed as opposition to humanities, there often exists an aura of fear/intimidation around STEM fields for many who see themselves as “non-scientists.” By incorporating writing – something humanities students are exposed to more often due to the increased prevalence of writing in those courses – into science courses, we can reduce that barrier to entry. Student familiarity to some part of the task at hand can improve learning outcomes and motivation (Soppe et al., 2005). In this study, students do in fact report feeling that this course was more “relatable” or “approachable” than other STEM courses, indicating that the approach may be beneficial for introductory science courses and may make a larger or more lasting impact on student learning of science content and especially their attitudes towards science. As always, we must acknowledge that we can only confidently state these takeaways for our particular sample of students, as we do not have sufficient evidence to make generalizable claims – however, this case study illustrates that writing pedagogy may be a promising technique for further investigation for the reasons discussed above.

5 Conclusions & Potential Implications

After a quarter-long writing-intensive introductory science course, the culmination of a year-long GE course, student attitudes towards astronomy improved in multiple ways – particularly a more nuanced and modern view of science as a field and scientists as people, and greatly increased confidence and belief in their own ability to engage with science. In interviews, students expressed directly that the science writing instruction was critical to their engagement and learning, essentially forcing them to develop a greater understanding of the material and helping them find purpose in course content through tasks that were both relevant to the real-world (e.g. interpreting science news) and relevant to their humanities-focused majors and prospective career paths.

Overall, this qualitative case study explored the effects of science writing on non-STEM major introductory students in a unique course, and found that there were many positive impacts, adding evidence to the idea that interdisciplinary pedagogy including a focus on writing skills may be useful for not only science majors, but also students learning about science who do *not* plan to pursue a STEM career. This is a first step towards gathering evidence for exploring and expanding writing pedagogy in science coursework, particularly in physics and astronomy where communication training is often absent. This course helped foster many desirable attitudes in students which point towards increased science literacy and breaking down stereotypes of scientists, and the following investigation provided evidence that discipline-based writing pedagogy in STEM courses has benefits in this unique sample of students and should be explored further with research and pedagogical interventions. Future work should include investigations into courses with a broader set of participants (e.g. a more typical introductory astronomy course, participants of multiple class levels beyond first-years) to determine if the claims in this paper are generalizable to a larger population.

6 Availability of supporting data and materials

The data set supporting the results of this article is not available in accordance with IRB protocols for this project.

7 Declarations

7.1 List of abbreviations

- GE: General Education
- JWST: James Webb Space Telescope
- STEM: Science, Technology, Engineering, and Math
- UCLA: University of California, Los Angeles

7.2 Ethical Approval

This study was conducted with approval from UCLA IRB under Protocol ID IRB#22-000440.

7.3 Consent for publication

Not applicable.

7.4 Competing Interests

The author(s) declare that they have no competing interests.

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7.6 Author's Contributions

B. Lewis: Conceptualization, data curation, formal analysis, investigation, methodology, project administration, visualization, writing – original draft. K. Supriya: Conceptualization, methodology, supervision, writing – review and editing. G. Read: Conceptualization, methodology, writing – review and editing. K. Ingraham Dixie: Conceptualization, methodology, supervision, writing – review and editing. R. Kennison: Supervision, writing – review and editing. A. Friscia: Supervision, writing – review and editing.

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