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Increasing Student Confidence in Writing: Integrating Authentic Manuscript Writing into an Online 8-Week Research Program

Choah Kim,[a,b] Kiam Preston, Jr.,[b,c,d] Alice Braga,[b,e] and Sarah C. Fankhauser[b,f]
[a]Harvard University, Cambridge, Massachusetts, USA
[b]Journal of Emerging Investigators, Chandler, Arizona, USA
[c]Morehouse School of Medicine, Atlanta, Georgia, USA
[d]National Eye Institute, Bethesda, Maryland, USA
[e]Department of Neuroscience, Tufts University School of Medicine, Boston, Massachusetts, USA
[f]Oxford College of Emory University, Oxford, Georgia, USA

Choah Kim, Kiam Preston, Jr., and Alice Braga contributed equally to this paper. Author order was determined by level of involvement in the initial development of the MPP.

In various formats, students at the secondary and postsecondary levels participate in multiweek authentic science research projects. There have been many papers explaining the operations of such programs, but few have provided explicit instruction on how to incorporate authentic communication practices into the student research process. In this paper, we describe how we integrated primary literature into an 8-week online research program for 8th to 11th graders. Each week, students were introduced to a specific section of a primary research article reflecting different stages of their research project, and they were guided on how to write that specific section for their own research paper. By the end of the program, students had an outline or first draft of a primary research paper based on their research. Following completion of the program, student participants reported greater self-efficacy and confidence in scientific writing. Here, we describe our approach and provide an adaptable framework for integrating primary literature into research projects.

KEYWORDS science literacy, primary literature, science research literacy, science writing

INTRODUCTION

Compared to the traditional way of teaching science, research-oriented science is thought to be more engaging, by involving students in answering novel scientific questions and thereby directly identifying themselves as scientists (1). Engaging students in authentic science inquiry has been a goal for both policy makers and educators for many years (2–4). Educators have thus sought to engage students from the elementary through college level in science programs, such as project-based science, science fairs, or integrated science research experiences (5, 6). The efficacy of these programs is clear: increased skill sets, development, identity, and retention in science, technology, engineering, and mathematics (STEM) (7). There have been many excellent reports of research programs and course-based undergraduate research experiences (CUREs), often with procedural notes on how to implement the experimental portions of the program. Engaging students in such a way helps them achieve competencies and skills, such as the ability to apply the scientific process, analyze and interpret data, and construct explanations. These skills add to the goals of secondary and postsecondary science education (2–4) of learning how to evaluate scientific literature, construct hypotheses and evidence-based conclusions, and communicate scientific information. These literacy processes are critical for student development as scientists, their science identity, as well as understanding the many roles that scientists have (8). What we find missing from the literature are explicit instructions on how to incorporate disciplinary literacy skills that reflect how scientists read, use, and construct primary literature as part of their experimental process (9, 10). Our past work has shown that early exposure for students to participate in the disciplinary literacy practices of writing and publishing a manuscript can increase their understanding of how scientific knowledge is constructed and foster their scientific identity, confidence, and interest (11, 12). These qualities are also the building blocks of proficient scientists. Writing skills are crucial for a wide variety of curricula or jobs and are particularly pivotal for scientific communication. Providing students with the opportunity to learn and

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Address correspondence to Journal of Emerging Investigators, Chandler, Arizona, USA. E-mail: sarah.fankhauser@emory.edu.
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refine their writing skills has the potential to boost their sense of self-confidence and belonging in STEM and will equip them with the tools necessary for their next career stages.

In this curriculum paper, we provide a model for incorporating authentic science manuscript writing into an extracurricular research program for middle and high school students. The Mini PhD Program (MPP) offered through the science journal *Journal of Emerging Investigators* (JEI) (www.emerginginvestigators.org), engages middle and high school students in the research process by providing the tools, mentorship, and community for students to publish their own scientific investigations and to improve their literacy skills. Traditionally, JEI has been an open-access journal publishing original research in the biological and physical sciences that is written by middle and high school students; MPP arises from the commitment to provide resources and mentorship to students from backgrounds underrepresented in STEM by providing the tools, mentorship, and community needed by any middle or high school student for pursuit of their own scientific investigations, publishing work, and building confidence in their potential to become scientists.

The MPP is a free, online, 8-week summer program with the goal of engaging students in a mentored publishing experience from the crafting of a scientific inquiry project to final peer-reviewed publication of a manuscript. The experimental investigation that students perform focuses on measuring the antibacterial properties of different household spices that students can find in their own homes. Students were mailed kits that included all the necessary scientific equipment and tools. Each week, facilitators met with students online to discuss research project progress, to help students perform their experiments, and to provide instruction on communicating research findings. Besides offering the possibility to perform scientific experiments, the MPP focused on analyzing and explaining the structure of a scientific manuscript with the final goal to provide accessible knowledge for both interpreting and conceiving a scientific publication.

While the experimental portion of the MPP is compelling, the integrated literacy instruction could be applicable to other teachers or instructors that are engaging students in research projects. Here, we describe how students engaged in literacy skill development each week by drafting a portion of their primary research paper. Students worked in small groups on weekly literacy assignments, which culminated in groups producing full-length scientific papers. Our preliminary survey analyses demonstrate that the program increased student understanding of the purpose of writing and publishing in scientific communication, skills in using and producing primary literature, and confidence in science writing. Although our program is geared toward younger scientists, the approach and materials may be adapted to more advanced students who are participating in science research programs or courses.

Intended audience

For this program, we enrolled 8th to 11th grade students nationwide from backgrounds underrepresented in STEM, who will be first-generation college students, and from disadvantaged backgrounds. However, the module description and tools for integrating literacy practices may be adapted for teaching more advanced students. Students were reached via e-mail sent to school counselors or teachers available in JEI contacts. Students were then recruited via online applications available on the JEI website, and such applications were subsequently screened by MPP organizers.

Learning time

The program consisted of 8 modules, all carried remotely by using a Zoom platform; each module started with a 40-min session to establish scientific background and to systematically guide students through relevant portions of an original scientific research paper. These lectures were followed by 1 h and 20 min of group meetings. Two to three students were paired, with a single facilitator with the aim to help and guide them through their scientific process, by both providing scientific feedback on their project for the course as well as during their process of manuscript writing. For the purposes of this study, we provided limited background on the experimental aspects of the program to highlight the literacy aspects of our program.

Prerequisite student knowledge

There were no prerequisites required for student enrollment. No prior knowledge or experience with the primary literature was expected.

(i) Learning objectives. Upon completion of the MPP, students will achieve the following learning objectives (LOs):

1. Conceptualize, plan, and execute a research project.
2. Understand the roles of writing and publishing in the scientific process.
3. Comprehend the common formulaic structure of a primary science article.
4. Develop skills in finding and using primary literature as part of the research process.
5. Develop confidence in scientific writing.
6. Construct a primary science paper explaining their scientific research.

Goals 2 to 6 represent the literacy-specific goals which are the focus of our study.

PROCEDURE

Materials

The program was conducted online in summer 2021 (27 students) and summer 2022 (16 students). Each week, students met online through the Zoom platform for experimental and literacy discussions as they prepared the writing of their own full-length papers on their experiments. For the purpose of our program, the experimental activities of both cohorts focused on characterizing the antimicrobial potential of common household products, such as spices.

The curriculum for the 8-week program incorporated use of a sample model paper published in JEI (13) to help students explore relevant content and methodology for their experiments. Students were first introduced to the anatomy of a primary research article, using our selected model paper, through assigned readings of manuscript sections corresponding to the lecture content of the week. For example, students were taught the content and tone of the methods section of a manuscript by allowing direct engagement with the methods section of the published model paper, which served to guide the students' writing of their own methods for their experiments. This strategy was applied for all sections of the primary research paper, and an additional article (14) was used to provide additional context for designing and planning experiments.

Each weekly module was concluded with a homework assignment designed to guide students through reading and interpretation of the model research article and for writing their own manuscripts. Each module was structured as described in Table 1; weekly sample assignments adapted to our curriculum topic can be found in the associated appendices in the supplemental material.

Student instructions

Students attended each weekly session over a virtual video platform (Zoom), where large and small group discussions were conducted. Students were provided with a lab notebook to record their experimental procedures, observations, and details throughout the course of the program. Students were given a postclass review and homework assignments to prepare for the content covered in the next weekly session. Assignments included worksheets to preview or review class content, performance of experiments, and writing of manuscripts. Students within the same small group communicated with each other to complete assignments and collaborated to write their manuscripts.

Faculty instructions

Facilitators worked with individual groups of 2 to 3 students each. Facilitators were provided with lesson objectives, copies of student take-home assignments, and leading questions to guide group discussions for each upcoming class. Facilitators met for half an hour before each weekly session for content overview. Facilitators also performed midweek check-ins by email or group chat with their student groups to discuss experimental progress and manuscript writing. The facilitator instructions are provided in greater detail in the appendices in the supplemental material.

Suggestions for determining student learning

Student achievement of the learning goals was measured through pre- and postprogram surveys (Appendix S9). Data from participants are described below in the Discussion.

Additionally, students completed homework each week. However, given that this program was a voluntary summer endeavor, homework was not graded. An example of week 1 homework is shown in Fig. 1. Examples of student papers can be found on the *Journal of Emerging Investigators* website, but individual participant papers are not provided, to avoid identifying participants.

Safety issues

Safety issues will be dependent on the type of experimental program that the faculty member uses. There are no safety issues with the literacy components of the program.

DISCUSSION

Field testing

(i) Ethics statement. The study was approved by the Emory university IRB (STUDY00000797).

We collected anonymous survey responses from student participants from summer 2021 (21 preprogram responses, 78% response rate); 13 postprogram responses, 48% response rate, and 2022 (10 preprogram responses, 63% response rate; 14 postprogram responses, 88% response rate). A preprogram survey was administered to students during week 1 of the 8-week program, and the postprogram survey was administered following the completion of week 8.

Surveys were designed to assess the outcomes of our literacy specific goals (LOs 2 to 6) measuring student understanding of the research process, scientific literacy practices, and confidence and identity in science. Here, we summarize the results for the literacy specific questions, but the entire survey can be found in Appendix S9. The survey was similar to that used and confirmed for reliability with a similar population of JEI student authors (12).

Evidence that students understood the role of literacy processes in science

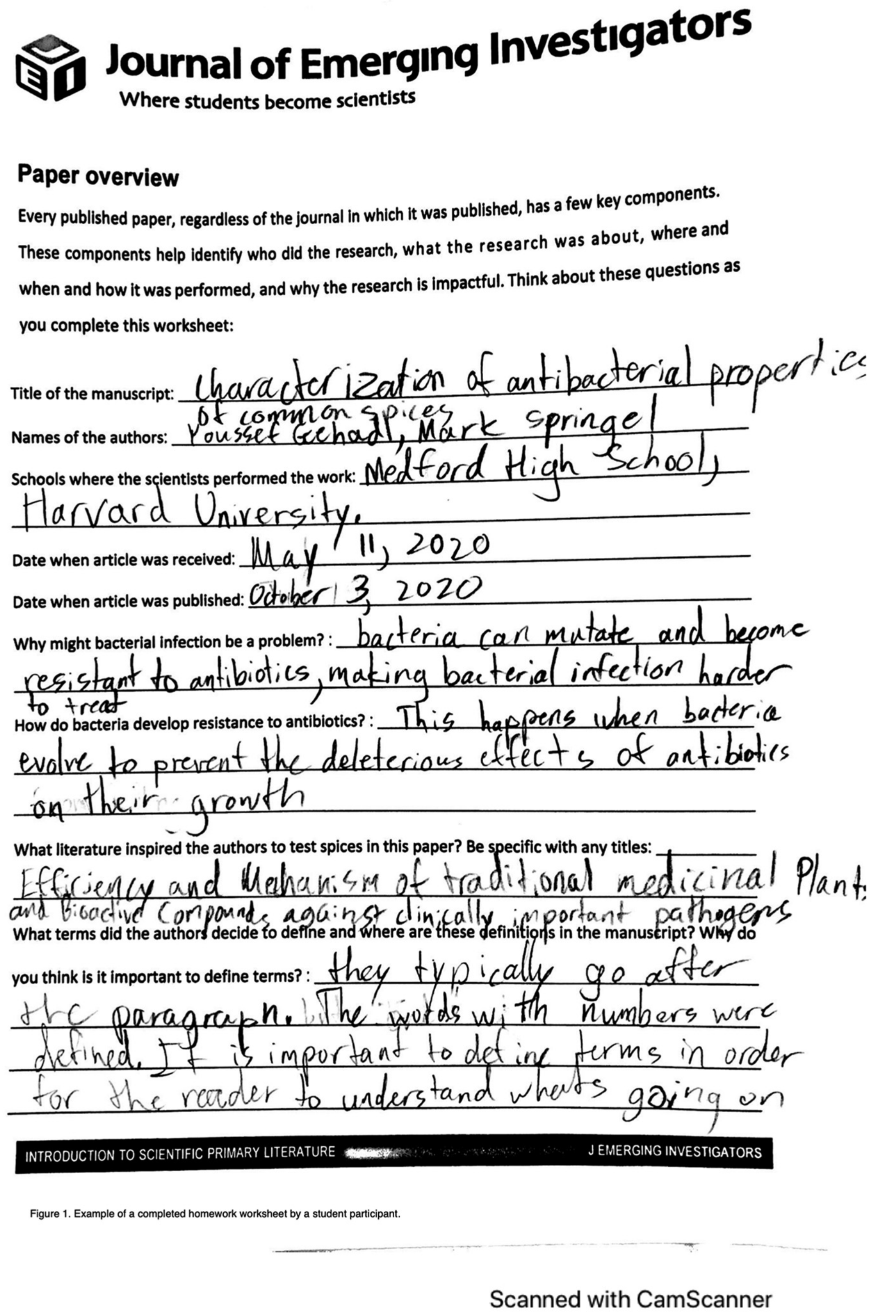
To investigate how students view the role of the primary literature within science, LO2, we asked questions regarding their understanding of writing, peer review, and publication within science. Responses were measured on a 5-point Likert scale (from strongly disagree to strongly agree). Compared to the preprogram survey, students in the postprogram survey reported a significantly higher response mean across the six questions (Table 2). Moreover, a greater percentage of students in the postprogram survey responded with "strongly agree" to the questions (Fig. 2).

Evidence that students developed efficacy in using and producing the primary literature

Five questions on the survey were intended to investigate changes in how students perceived their own ability in using and producing the primary literature as part of their research process (LOs 3 to 5). Responses were measured on a 5-point Likert scale (from strongly disagree to strongly agree). The

TABLE 1
Overview of literacy skill integration in the 8-week MPP

Module	Literacy skill development	Session activity	Homework
1. Introduction to the research process (Appendix S1)	Discover how the structure of a primary research article reflects the steps of the scientific method	Students are assigned to come to the first class having searched for a video or article about their favorite researcher or scientific figure, their career, and any challenges and impact of their work	Article scavenger hunt that includes a list of questions meant to help students conceptualize the anatomy of a research article (10)
2. Introduction to the experimental topic (Appendix S2)	Learn about bacterial biology and how to extract information from primary research articles	During class, students will discuss the JEI primary article (13) assigned for homework and their understanding of experimental content with groups	After this session, students will contribute to building a group glossary, defining terms which are relevant to the experimental topic and can be referenced for writing their manuscripts
3. Experimental design and controls (Appendix S3)	Learn how to formulate a research question and hypothesis using preexisting literature, and the importance of positive and negative controls	Students will work with groups to brainstorm their experimental questions and variables to test, applying knowledge from reading published JEI articles	A worksheet and reading of a suggested primary JEI article (14) are used by students to list the materials and experimental procedures that will be necessary for their experiments
4. Writing a Methods section (Appendix S4)	Learn the tone and purpose of writing a methods section in a way that allows anyone to replicate the experiments	The primary article's Materials and Methods section is dissected to explain each step to the students	Students will explore their experimental Materials and Methods and outline them in the worksheet
5. Career panel (Appendix S5)	Hear real-life examples of different career trajectories and build confidence in scientific independence through ongoing literacy and writing practice through the MPP	Students will have the opportunity to speak with panelists about their chosen career paths, research interests, and most recent projects or publications	Students will continue progress on manuscript writing
6. Writing a Results section (Appendix S6)	Practice reading and writing experimental results, organizing results in tables, and presenting data in figures	Students will discuss their data, the best ways to present them, and apply this to completing their own Results sections	The JEI primary article (13) Results section is used as an example to guide the students on how to describe each critical step of their experimental process in detail and the results and observations obtained from their experiments
7. Writing a Discussion section and Introduction (Appendix S7)	Learn how to contextualize the study and how to discuss the conclusions, significance, and limitations of their data; gather background information from existing literature to write introduction sections	Students will start researching scientific literature for references to their work and outline their discussions and introduction sections with their groups	Students will continue writing their Discussion sections started during class; a worksheet is also provided to help the students organize results data for their figures and to continue writing their introduction sections
8. How to write an abstract; learn about the peer-review process (Appendix S8)	Learn the purpose and function of an abstract and steps of the peer review process before publication; practice clear communication of scientific research with peers	Students will start with gathering the main ideas from their manuscripts to write their abstracts with their groups; after this activity, student groups are paired with another group to share practice communicating their research findings	Student groups will continue to reference the original article (13) as well as other published literature to complete their manuscripts and submit their work to JEI following the end of the program; students undergo the peer review process after submission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Where students become scientists

Paper overview

Every published paper, regardless of the journal in which it was published, has a few key components. These components help identify who did the research, what the research was about, where and when and how it was performed, and why the research is impactful. Think about these questions as you complete this worksheet:

Title of the manuscript: Characterization of antibacterial properties of common spices

Names of the authors: Youssef Gehad, Mark Springel

Schools where the scientists performed the work: Medford High School, Harvard University.

Date when article was received: May 11, 2020

Date when article was published: October 3, 2020

Why might bacterial infection be a problem?: bacteria can mutate and become resistant to antibiotics, making bacterial infection harder to treat

How do bacteria develop resistance to antibiotics?: This happens when bacteria evolve to prevent the deleterious effects of antibiotics on their growth

What literature inspired the authors to test spices in this paper? Be specific with any titles: Efficiency and Mechanism of traditional medicinal Plants and Bioactive Compounds against clinically important pathogens

What terms did the authors decide to define and where are these definitions in the manuscript? Why do you think is it important to define terms?: they typically go after the paragraph. The words with numbers were defined. It is important to define terms in order for the reader to understand whats going on

INTRODUCTION TO SCIENTIFIC PRIMARY LITERATURE J EMERGING INVESTIGATORS

Figure 1. Example of a completed homework worksheet by a student participant.

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FIG 1. Example of a completed homework worksheet by a student participant.

postprogram survey response mean was significantly higher than the preprogram survey response mean, indicating that students improved their abilities and confidence in using and producing primary literature (Table 2, Fig. 3).

Constructing a primary science paper explaining their own scientific research

As evidence that LO6 was achieved, all groups completed the program with a draft or outline of their research paper. Although submission of a manuscript for publication was not a requirement of the MPP, student groups were strongly encouraged to complete their manuscripts with their groups and submit their work for publication. In 2021, 5 of the 10 student groups submitted manuscripts to JEI; these manuscripts are currently in revision or have been published. In 2022, two student groups submitted their manuscripts, while other groups are in the process of preparing for submission.

Qualitative assessment of student perceptions

The following questions were asked on the postprogram survey administered after the last week of the MPP: "How did writing a manuscript during the program affect

TABLE 2
Question means across the pre- and postprogram surveys[a]

Factor and associated questions	Survey result (mean ± SE)		*P* value
	Preprogram	Postprogram	
Understanding the role of literacy skills in science • Writing about my research helps me understand the science better • Peer review improves the accuracy of the science in a paper • Peer review improves the communication of the science presented • Peer review can give scientists different ways to understand their science • Publication is important because it helps a scientist share his or her science with a broader audience • Publication is important because the science in a paper could be used by another scientist in his or her project	26.5 ± 0.41	27.6 ± 0.49	0.039
Abilities in using and producing primary literature • I am able to generate a research question to answer • I am able to figure out what data/observations to collect for a research project • I am able to create explanations for the results of my science • I am able to use scientific literature and reports to guide my research • I am confident as a scientific writer	18.45 ± 0.68	20.7 ± 0.73	0.011

[a]The scale for questions was 1 to 5 was from strongly disagree to strongly agree. Means and standard errors are reported; *P* values were determined from a one-tailed *t* test.

your understanding of the scientific method? If it made learning the scientific method easier or harder, how so? Did it change the way you think about what being a "scientist" means?"

There were 27 responses from the postprogram survey administered to both cohorts. These responses were separated when a clear transition from one thought to another thought was present, resulting in 47 distinct comments from the respondents in the 2021 and 2022 cohorts. Comments were thematically coded using an inductive approach to reveal 6 codes (Table 3).

The first part of the question asked students to reflect on how writing a manuscript affected their understanding of the scientific method. The 21 comments related to this question coalesced under one code "Greater understanding of the scientific method" and indicated that students thought that literacy instruction of the program deepened their understanding of the scientific method. For example, one student mentioned, "Writing a manuscript affected my understanding of the scientific method by making it more sense to me. It made learning the scientific method easier because I did a proper experiment following the steps of the method."

Students responded in three different ways to the prompt, "Did it change the way you think about what being a 'scientist' means?" The majority of students expressed the idea that they now understood that scientists have many roles. For example, one student mentioned, "And it changed the way I think of scientists. It is not just doing science experiments it is much more." A few students expressed that they have a different perception of who can be or is a scientist, with one student noting, "I think it's very easy for individuals to visualize a scientist as being a middle-aged white man in a lab coat, but this program helped me realize that even I, underrepresented as a black woman, being just a teenage girl, not wearing a lab coat, can still be a scientist because of my curiosity and love for science."

Although not explicitly prompted, nine students made comments on how the program impacted their writing. These comments were grouped into two codes, with the majority of the comments falling into the code of skill development, where students expressed the idea that the program affected their capacity to produce scientific writing. For example, a student noted that, "Writing a manuscript during the program helped me to understand the characteristics and required research necessary to have a credible and well-written paper." Two students mentioned that the program made writing more enjoyable for them.

While these student responses did not directly assess our intended learning objectives, we found it important to examine how the students perceived their experience in their own words. We are encouraged by the comments that indicated that students saw the roles of scientists more broadly from this experience, and we hypothesize that having the integrated literacy instruction facilitated this broader-based perception.

Conclusions

Together, these student responses and survey data revealed the following promising preliminary conclusions:

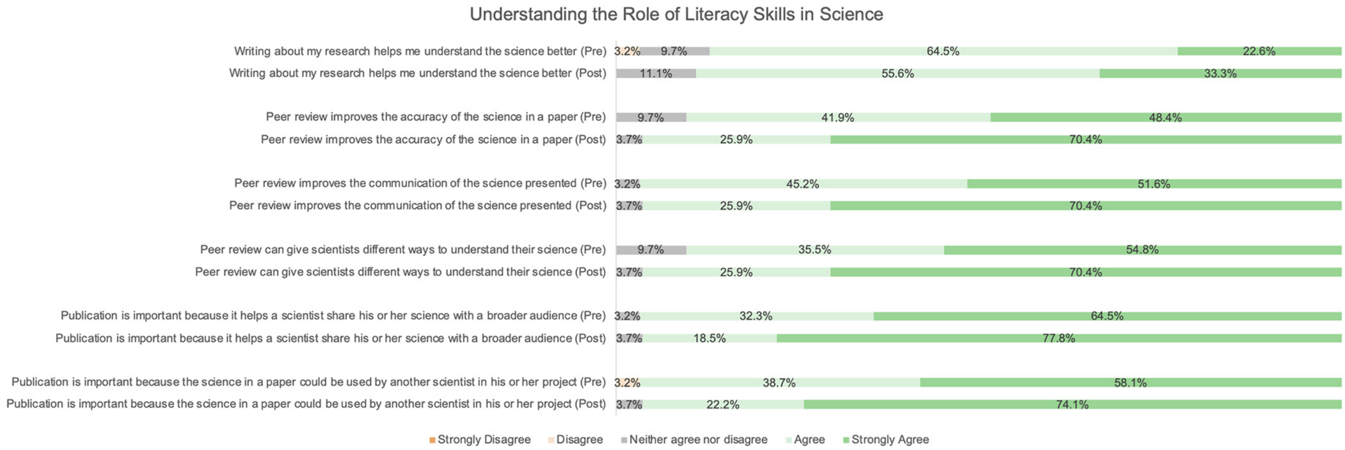

FIG 2. Understanding the role of literacy processes in the research process. Pre- and postprogram survey responses from student participants.

1. Students developed greater understanding of the role of writing, peer review, and publication in the scientific process.
2. Students developed their own skills and confidence in scientific writing.
3. Students gained a broader view of the roles and identities of scientists.

Based on our field testing, our curriculum contributed to the scientific writing skill development of students who engaged in the program. In addition to the descriptive improvements in scientific writing perceived by students, 50% of the summer 2021 cohort of students submitted their papers for publication. A majority of these students (>80%) indicated that they could not have submitted a manuscript for publication without the mentorship of this program, establishing the curriculum's effectiveness in improving the scientific literacy and writing skills of participating students.

Points 1 and 2 above were directly related to our stated LOs, but point 3 was an exciting unintended outcome. Past studies have shown that students who participate in peer review and publication of their research gain broader understanding of the role of literacy skills within research and develop their own self-confidence and efficacy in science (11, 12, 15). Our data expanded upon this and demonstrated growth across these metrics without having gone through the publication process, suggesting that the writing and literacy activities can facilitate some growth. Additionally, this program helped students expand their perceptions of what scientists do and who can be a scientist. While this may not be fully attributable to the literacy instruction, a few student comments revealed that students came away from the program with the idea that being a scientist means also being a communicator.

There are hundreds of programs that engage high school and college students in science research each year (16–18). Our program, which provides a model for incorporating authentic disciplinary literacy skills of reading, applying, and producing primary literature, can be used to enhance the student's research process, develop their communication skills, and expand their understanding of what science entails.

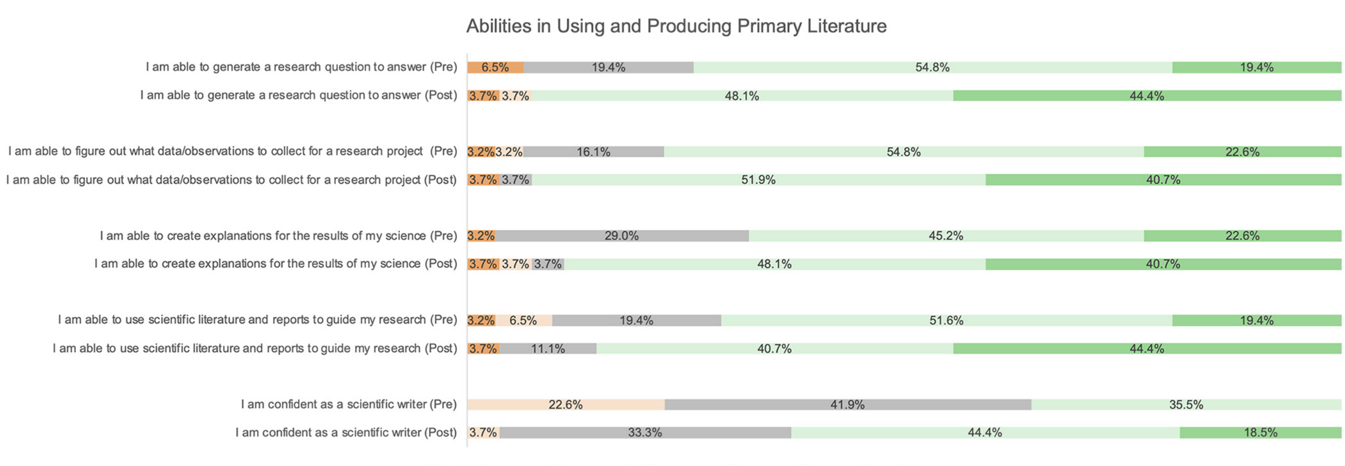

FIG 3. Ability to use and produce primary literature. Pre- and postprogram survey responses from student participants.

TABLE 3
Codebook for student responses

Code or subcode and no. of comments			
Code	**Subcode (if applicable)**	**Description**	**Example**
Greater understanding of the scientific method (21)		Student expresses having a deeper or better understanding of the scientific method through writing	"Writing a manuscript during the program helped me understand the scientific method in a much easier way, as the structure of the manuscript served as a great basis. Knowing the steps I would have to take and what I would have to note for the paper allowed me to be conscious of what I was doing with the experimen and developing a method."
Effect on perception of scientists (18)	Roles of scientists (12)	Student expresses learning the various roles and responsibilities of a scientist	"I just think it made me look at scientists more connected to their writing than I originally thought."
	Identity of scientists (5)	Student expresses an opinion on who can be a scientist	"It made me realize that you don't have to be a scientist with a white coat and goggles working in a lab to be a scientist and use the scientific method."
	No change (1)	Student states that the program had no impact on their idea of scientists	"I don't think it changed my perceptions of what it means to be a scientist, but it certainly helped me to begin my journey to becoming one!"
Effect on writing (9)	Enjoyable (2)	Student expresses that the program made them enjoy writing more	"Writing a manuscript is very challenging and I liked it as every moment when I add something in the paper."
	Skill development (7)	Student expresses that they developed their own writing skills	"It also helped to learn the format that the scientific community shares research in peer-reviewed journals."

(i) Limitations. The program described here enrolled a limited number of students to ensure an adequate mentorship; consequently, the sample size we had available for the survey analysis was limited. Moreover, as pre- and postprogram surveys were administered anonymously in order to allow students to freely answer any questions, we were not able to perform a paired statistical analysis that would have provided further insight on the progress made for each student. In the future, increasing our sample size and allowing for matched analysis will provide additional insight into the outcomes of this type of program. Finally, the program comprised both an integrated literacy approach as well as a hands-on research component; thus, we cannot discern with absolute certainty in this study how those two components differentially impacted student outcomes.

(ii) Possible modifications and future directions. There are several ways in which the program can be modified for audience or course structure. In our model, students worked in groups of two to three, which could be increased or decreased depending on the total number of students in the program. Additionally, while we had several facilitators, the student-to-faculty ratio could be modified depending on the number of faculty available to lead the program.

A more substantial modification, and one that would make our work applicable to others, is the ability to adapt our curriculum to more advanced students. With older students, greater experimental freedom can be incorporated into the research process. In our program, students worked within a set theme, but advanced students could likely develop more independent projects. For example, some classroom research courses have student groups design and execute their own research projects throughout the course of the semester (19). In other cases, college programs may engage high school students in extended independent research experiences (20). Providing the scaffolded and integrated manuscript writing described here could even be incorporated into course-based undergraduate research experiences (CUREs). A key tenet to CUREs is that students make discoveries that are relevant to the scientific community (21). By guiding students through manuscript writing, students must be able to situate their work within the broader scientific community, thus determining the broader relevance of their research. Given the number of undergraduate research journals, providing undergraduates the opportunity to publish their work is not an unattainable goal; others have shown that the impact of CUREs is greater when students have the opportunity to disseminate their results (22). Providing students authentic literacy instruction, and using relevant model papers in the process, could further develop student research skills.

For the future of our program, in addition to expanding the number of participants and mentors, we are planning small but impactful changes in our curriculum to better prepare students for the types of science communication they will be exposed to in college and beyond. In the previous iteration of MPP, student groups paired up to exchange readings of their research abstracts. This activity was meant to increase student interactivity and to introduce the discussion and spoken aspect of science. We will build on the idea by integrating a simple oral component where students develop an "elevator pitch" that will be a quick and digestible project synopsis. For students, a 30- to 50-s talk is an effective way to discuss their research within the MPP, as well as to anyone in the outside world, including peers, teachers, and possible college admissions interviewers. Many graduate programs across the country are focusing on shorter and simpler talks, such as an elevator pitch, for communication of science to a more broad environment. For example, the National Eye Institute at the National Institutes of Health has begun 3-Minute Talk competitions at their yearly Focus on Fellows meeting with the goal of capturing postbaccalaureate, graduate, and postdoctoral research in the shorter and simpler mode of communication we also plan to achieve (23). Adding an oral component to our program would give students another way to develop their scientific communication skills and engage with a scientific community in ways that reflect what they will experience in college and beyond.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 3.3 MB.

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