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Developing Scientific Communication Skills Using Primary Literature in an Undergraduate Cell Biology Course

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Being able to communicate scientifically is an important skill for students graduating with a science degree. Skills used in future graduate school and careers for science majors include oral and written communication, as well as science literacy and being able to create figures to display information. There is a consensus that these skills should be taught throughout an undergraduate science curriculum; however, many instructors have cited insufficient time to cover skills and develop materials to effectively incorporate these skills, especially into lower-level content-focused courses. Here, we present an active curriculum that can easily be incorporated into any content-focused undergraduate Cell Biology course. The curriculum is designed around scientific literature that engages students in a multitude of active learning activities to develop different types of scientific communication skills. This curriculum not only develops student skills and self-efficacy in scientific communication, it also engages them in course content and stimulates their interest in research. While making changes to a course to include scientific communication can be difficult, making small changes, such as addition of this curriculum to an already-existing content-focused course, could make a big difference in the skills and attitudes of early undergraduate science students.

KEYWORDS scientific communication, scientific literature, primary literature, communication skills, cell biology, undergraduate cell biology

INTRODUCTION

It is critical for students to learn communication skills throughout an undergraduate curriculum, along with the content knowledge they gain in classes. Communication skills are important for any future career that science students may go into; health care workers, scientists, and many other science professionals must be able to communicate difficult concepts to a lay audience, as well as communicate effectively within their own discipline (1–6).

There have been many studies on implementing strategies to increase student skills and confidence in science communication to a general audience (6–10); however, here we focus on communication skills within a science discipline, which we refer to as scientific communication skills.

Since communication is an important component of scientific careers, it is also important to expose students to these activities early in their education to give them a sense of what those careers entail. Many students who take introductory courses do not continue to finish their science degrees. Therefore, many students leave science majors before fully understanding the possibility of career options and the skills needed for those careers beyond just content knowledge (11).

Many educators report that it is important to develop these types of skills throughout the undergraduate curriculum; however, many lower-level courses are often much more content-focused (3, 4, 12–14). In fact, there have been calls in higher education to explicitly integrate these skills into science curricula (6, 15). Interestingly, it has been reported that students perform better in lower-level, content-focused classes when communication and scientific process skills are taught along with content and that incorporating these skills actually helps reinforce course content (16–20). Why then do faculty not focus more on the development of these skills in their courses? Many reasons cited include an expectation to cover content and commitments for both in-class time and for development of course materials (13).

Our goal was to create a resource that could be easily implemented into a content-focused course to develop scientific communication skills. Scientific communication skills have been incorporated into courses in many ways, including reading scientific literature, oral presentations, mock research projects, scientific writing, and many more examples (17, 21–30). Incorporating a diversity of science communication modalities

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may contribute to increased student learning by making scientific content easier for students to access and making the content relevant to their lives (31). Here, we report on a suite of activities designed to develop student oral, written, and visual scientific communication skills within a lower-level content-focused undergraduate Cell Biology course. The curriculum contains activities aligned to three scientific papers that can be distributed throughout the semester and culminates in a poster presentation of a scientific paper of student choice. In alignment with universal design for learning (31), the activities were designed to offer multiple ways to engage with and sustain interest with the material, such as individual worksheets, collaborative work, and the "real-world-based" scientific poster. These activities also incorporate multiple methods of expression and communication and allow instructors to assess students' proficiency in a variety of ways. This curriculum can be implemented in an in-person or virtual classroom. We found that students developed scientific communication skills and confidence in these skills throughout the semester.

Ethics statement

This study was deemed exempt from institutional review board (IRB) review by the Boston College IRB Office for Research Protections (IRB 21.092.01-1). Boston University determined that the project was not classified as research and did not need to go through the IRB review process. Students completed an informed consent process before filling out surveys.

Intended audience and prerequisite student knowledge

The activities presented here were designed for undergraduate Cell Biology students in biology or biology-related majors who had already completed the introductory biology course sequence. Students should be familiar with introductory concepts regarding the central dogma (DNA, RNA, protein, transcription, translation). The paper assignments complement material covered in Cell Biology, so students should receive some instruction on concepts covered in assignments prior to reading each scientific paper. The content-focused learning objectives for each paper are included in the assignment instructor resources (see Appendices S1 to S3 in the supplemental material).

Learning time

The intended use for the assignments was to complete each of the three paper assignments within two 1-h discussion periods. Over the course of three papers, this would be six total hours of questions related to each paper. Prior to class periods in which papers were discussed, students were expected to have read through the paper, requiring approximately 1 to 2 h for each paper. Additionally, two discussion periods were designated for working on the poster presentation, with the expectation that some time outside of class would be devoted to working on that project as well. One discussion section was used for students to view their peers' recorded poster presentations. At the introduction of the project, we recommend having a brief class discussion about group work norms and providing resources, including language, for problem-solving collaboration issues. Additionally, it is recommended that there be a session dedicated to how to read papers and how to find papers and one or two sessions where students have class time to work on their projects together. In practice, these assignments could be used in a discussion section as explained, or incorporated throughout a lecture course, as explained below.

Learning objectives

After completing the paper assignments and poster presentation, it is expected that students will develop both skills and confidence in the following areas of scientific communication:

- Reading a primary scientific paper, including identifying experiments, analyzing figures, and summarizing main conclusions.
- Writing a summary of results from a primary scientific paper.
- Orally explaining data from a primary scientific paper.
- Developing visual representations of scientific concepts.

PROCEDURE

To develop scientific communication skills, we designed activities around three primary scientific literature articles throughout the semester. The articles were related to the content being covered in Cell Biology at that point in the semester. The Patterson 2002 paper covers fluorescence and microscopy with an emphasis on how green fluorescent protein works (32). The Xie 1998 paper covers the central dogma by analyzing cancer-causing mutations in the Sonic Hedgehog pathway (33). Finally, the Woods 2017 paper covers cell signaling through mutations that affect signaling by focal adhesion kinase (a tyrosine kinase) (34). Methods covered by these papers include many commonly covered methods in Cell Biology courses: immunofluorescence, fluorescence microscopy, fluorescence *in situ* hybridization, sequencing, cell culture, Western blotting, and mouse experiments.

The paper assignments were made according to two different schedules in the two different classes. In one class, each paper was divided into two components and implemented in discussion sections that ran parallel to course lectures. In the other class, each paper was divided into multiple components that were implemented throughout the lecture classes. The modular format of the paper assignment questions makes them amenable to flexible course formats. The instructor documents included detailed instructions for questions relating to every

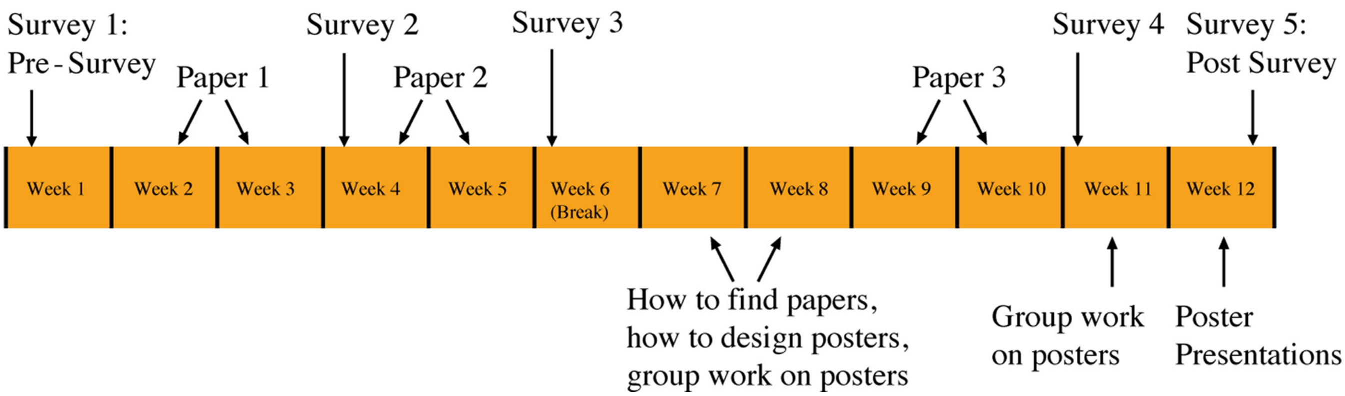

FIG 1. Study design. The preactivity survey was administered, and then a survey was administered after the completion of assignments for each of the three papers assigned throughout the semester. The semester culminated in poster presentations and then a final survey at the end of the semester.

figure of each paper, including estimated time allotted for each question, allowing for flexible integration into any type of course format.

The semester concluded in a poster project to assess achievement of each of the scientific communication skills. Students worked on these poster projects throughout the second half of the semester. There was a session early in the semester devoted to learning how to find and read scientific papers, a second session where students were introduced to the project and had time to work with groups, and a third session where students had time to work with groups closer to the end of the semester. The poster project was due at the end of the semester. Poster presentations were recorded and posted to a discussion board where students could view other students' submissions. Students had to watch and submit comments on three of their peers' presentations. We decided to hold the poster presentations virtually and asynchronously due to the pandemic, but this format could be adapted. However, we did find that video recordings were helpful for scoring, and we recommend maintaining recordings even if an in-person poster session is implemented.

Additionally, surveys were distributed throughout the semester to obtain information on student self-efficacy and attitudes toward scientific communication skills (Appendix S4). The full timeline of the semester by week is illustrated in Fig. 1. A preactivity survey was distributed before any paper assignments were completed. Three surveys were distributed throughout the semester, one after the completion of each of the three paper assignments. A postactivity survey was then distributed after the completion of the poster projects.

Faculty and student instructions

The instructor guide for each paper assignment included the content learning objectives for each paper, assessment questions, and in-class discussion questions (Appendices S1 to S3). Each instructor guide was created using the backward design process (35). Learning objectives were first formulated around each paper, and then assessment questions were designed to assess the attainment of each learning objective. Finally, in-class questions were created to help students learn, with the goal of being able to successfully complete the assessment questions. Suggestions for active learning strategies were specified for each of the in-class questions, along with the approximate amount of time each question and section should take. Answers to in-class questions and quiz or exam questions are included in the faculty and student instructions (Appendices S1 to S3). Annotated figures in instructions can be used or modified for presentations.

For the poster project, the supplemental materials contain project guidelines, a poster presentation rubric, and a group feedback form (Appendices S5 to S7). These are meant to serve as guidelines and can be modified depending on the course structure and expectations.

Instructor preparatory work is limited to spending time to become familiar with the paper, instructions and answers, and assembling any extra material they want to present.

Suggestions for determining student learning

There are several formative and summative assessments to assess student achievement of the learning objectives for these activities. Included in each of the paper assignments are both formative and summative assessments that address the scientific communication learning objectives as well as the content learning objectives for each paper (Appendices S1 to S3). In addition to quiz or exam questions for summative assessments, a poster presentation is used to assess achievement of each of the scientific communication skills. A rubric for the poster presentation is provided in Appendix S6.

Sample data

The supplemental material (Appendices S8 and S9) includes examples of student work that obtained high scores, including examples of student visual demonstrations created during one of the in-class active learning sessions, as well as examples of student posters.

DISCUSSION

Field testing

The activities were administered in two undergraduate Cell Biology courses at two different private universities, Boston University and Boston College, in Spring 2021 by two different instructors. In one class, paper assignments were incorporated into hybrid discussion sections. In the other class, paper assignments were distributed throughout online lectures. Students were given five surveys throughout the semester; a preactivity survey, surveys after each of the three paper assignments was completed, and a postactivity survey after the final poster presentation (Appendix S4). There were a total of 156 students that completed all surveys across both classes.

For the purposes of this study, we combined the data across both classes due to the similarity of students across classes. Both universities are private universities in Boston, MA. Both classes were large classes of approximately 100 students each. They were both intermediate-level classes consisting of mostly sophomores. Each class read the same three papers over the semester, and both classes were provided with similar materials for instruction and assessment.

One concern with spending class time on skills rather than content is that it may take away from learning the content (13). Students were asked about this in the last survey. Students reported that they felt spending time on scientific communication skills did not interrupt their learning of the course material; in fact, they reported that it helped them learn course content and engage with the content. We do note, however, that we do not have previous data for comparison, so these data are only representative of student perceptions, and further examination would be required to draw conclusions. Students agreed to the following statements on a Likert scale of 6 points: (i) reading primary scientific papers that related to course content enhanced my understanding of the content covered in class (4.8/6); (ii) it is useful to read scientific papers that relate to class content (5.1/6). Below are quotes from student surveys about how it was useful to connect course content to scientific papers and scientific communication skills.

> "When we read about topics that related to what we learned it showed me exactly how it can be applied and it added to my understanding of how that protein or pathway functions."
> "The content is closely related with class material and helps me to understand more how to read a scientific paper."
> "Reading about how the content covered in class was applied in the experiments and studies helped me better visualize and understand it."

Evidence of student learning

Student learning and skill development were assessed using assignments designed for each of the three papers (Appendices S1 to S3). The paper assignments included questions for students to develop and demonstrate each of the learning outcomes. The average score across both classes for all three paper assignments was 96%, demonstrating successful progress toward the learning objectives at the formative assessment stage. Content knowledge from the papers was also assessed in exam questions as summative assessments. Example exam questions are included in the instructor documents for each paper (Appendices S1 to S3). On average, 76% (±19% [standard deviation]) of students in both classes answered questions related to the papers correctly. In comparison, the average exam score across both classes was 83% (±6%). In conclusion, averages for paper questions were similar to the average performance on general knowledge questions, showing sufficient achievement of the content learning objectives at the summative assessment stage.

Development of all scientific communication skills learning outcomes was also assessed by a summative assessment in the form of the poster presentation. Students worked in groups of four to five students to choose a primary scientific article on a topic related to class, and they presented the results from the paper in a poster presentation (the rubric is included in Appendix S6; also, see sample student posters in Appendix S9). The average score across both classes for the poster presentations was 91%, demonstrating excellent achievement of scientific communication learning objectives at the summative assessment stage. The poster presentation assessed achievement of all learning objectives: reading a primary scientific paper, analyzing data in a primary scientific paper, drawing conclusions from a primary scientific paper, writing a summary of results from a primary scientific paper, orally presenting data from a primary scientific paper, and creating visual representations of scientific concepts.

Students were asked about which components of the class were most beneficial to them in learning and gaining confidence in scientific communication skills. Iterative coding of their responses revealed six course components that students felt contributed the most to the improvement of their communication skills: the quizzes, the poster project, the paper assignments, participating in class, explaining concepts to peers, and discussions with peers and instructors (Table 1). The most-often-identified course component was the poster project (44% of coded responses). Students cited the opportunity to practice

TABLE 1
Aspects of the courses that students described as improving their scientific communication skills

Course component	% of responses
Poster project	44%
Paper assignment	23%
Discussions	14%
Participation in class	10%
Explaining content to peers	7%
Quizzes	2%

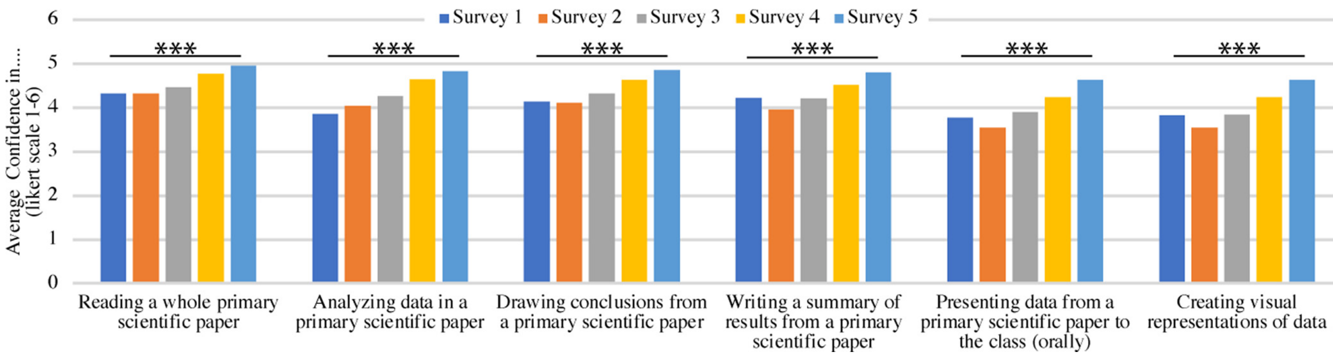

FIG 2. Student self-efficacy in scientific communication skills throughout the semester. Student confidence in a variety of scientific communication skills practiced and developed throughout the semester is summarized. Self-efficacy was self-reported in the five surveys throughout the semester. Data were compared for each question by related samples with Friedman's two-way analysis variance by ranks. $n = 156$.

or demonstrate their skills independently in a "real-world scenario" made the poster project valuable.

We also measured student self-efficacy of the learning objectives in five surveys distributed throughout the semester (Fig. 2 and Appendix S4). Student self-efficacy increased over the semester for all learning objectives. The data were compared by a related-samples Friedman's two-way analysis variance-by-ranks tests. If the null hypothesis was rejected, pairwise comparisons were made and significance values were adjusted by the Bonferroni correction for multiple tests (significance values are reported in Appendix S10). Interestingly, we found that for some of the learning objectives, students decreased in confidence or did not increase in confidence from survey 1 to survey 2. This may demonstrate the Dunning-Kruger effect, which suggests that novices often overestimate their own ability (35). Since survey 1 was distributed before students had any exposure to the skills, they may have overestimated their confidence in those skills and readjusted their perspective for survey 2 after being exposed to assignments where they had to use those skills.

We asked students if their interest in research or a career in scientific research changed during the course of the semester and to explain why in a qualitative question in survey 5. Sixty-four percent of coded responses indicated no change in student interest in research, while 31% of responses indicated an increased interest in research or research careers (Fig. 3). A small proportion of responses (3%) indicated a change in interest but were not clear about the direction, and 2% of responses showed a decrease in interest in a research career. Student quotes suggested that interest in research increased because of increased self-efficacy and understanding about the research process in terms of techniques, diversity of topics, and broader impact (Table 2).

At first glance, the lack of change in interest level was surprising; however, of the responses that indicated no change, 33% cited that they were already interested in research, and 14% indicated that they were interested in a medical or clinical career. This likely reflects the population of an intermediate-level biology course at a research-heavy institution; many students take this course as part of a pre-medical school track. These assignments may result in a change of interest in research in a different population, such as introductory or nonmajors courses. These data also suggested that many students in the course believed that a medical career was exclusive of a research career, or that reading and interpreting papers may not be a part

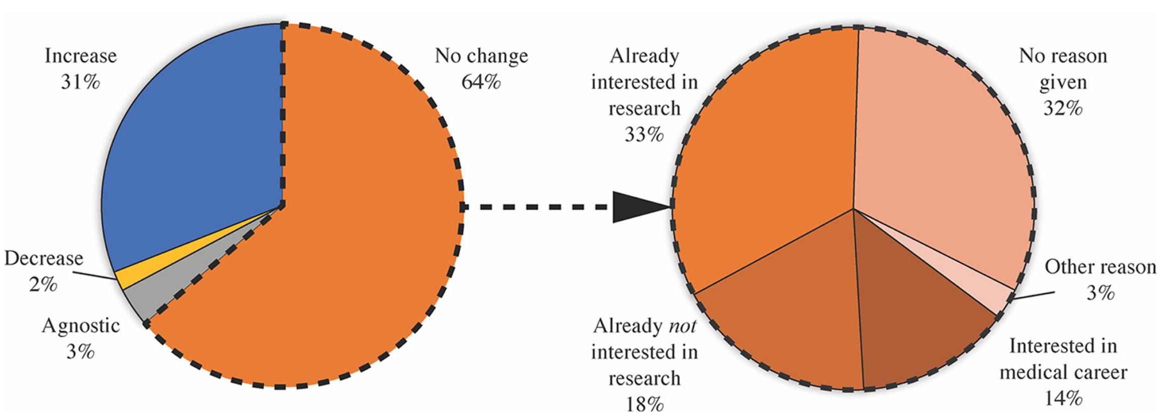

FIG 3. Most student interest in research and research careers did not change. Of students who reported no change to their interest ($n = 72$ of 113), 33% stated that this was because they were already interested in research prior to the course. Other reasons for no change included commitment to a clinical career or no interest.

TABLE 2
Representative student quotes describing why their interest in research increased[a]

Quotes by students	
"I feel **more confident in reading scientific papers** so I may read a few more in topics that interest me."	"Because, especially through the poster projects, I saw that **there is a lot of cool niches in research.**"
"Because I was not confident in reading papers but **now I know exactly how to attack these papers effectively** making me more open to a career in research."	"I realized that **there is so much behind these papers:** lab work, team communication, computations, etc. Learning cell biology this semester, I learned **a new side of biology that I had not known before.**"

[a]Boldface was added by the authors for emphasis.

of a medical career. Additionally, student quotes showed a lack of understanding about what a research career entails.

> "I have never been very interested in sitting down and doing lab work just because I'm a very hands on person. The class didn't really change that mindset at all."
> "But I still think that the social aspect of a clinical job is a key component for me and research lacks it."

These quotes, and the idea that a career in medicine is exclusive of a research career, could present an opportunity to talk more explicitly about the training for a career in research or the myriad of ways that medical careers interface with research.

We were also interested in whether students who reported increased confidence in multiple areas of scientific communication were also students that had an increased interest in research. We categorized students with an increase in confidence as any students that increased confidence by any amount in seven of the nine tested categories from survey 1 to survey 5 (other surveys were excluded, for simplicity). We categorized students with an increase in research interest as any student that increased agreement from survey 1 to survey 5 to the question "I am interested in research (for example, reading research papers, attending research seminars, conducting research)." We saw a significant correlation between students with increased self-efficacy in scientific communication skills and those that reported increased interest in research, based on chi-square analysis (two-tailed P value = 0.0115).

Possible modifications

The way these activities were administered in these two classes is a testament to how flexible the structure can be. The materials provided allow students to complete the assignments in a virtual or in-class environment, synchronously or asynchronously, in groups or individually, and each assignment can be completed in one session or spread across multiple sessions. The assignments could also be modified for level. For instance, we could imagine eliminating some more difficult questions and aiming this at an introductory-level biology course, or adding in more questions to bring the assignments to a higher level.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 5.3 MB.

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