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A Framework & Lesson to Engage Biology Students in Communicating Science with Nonexperts

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Abstract

Communicating science with nonexperts (SciComm) is an important scientific practice. SciComm can inform decision making and public policies. Recently, seminal reports have indicated that SciComm is a practice in which students should engage. Unfortunately, students have few opportunities to engage in SciComm, partially due to the absence of a framework that can help instructors facilitate such activities. We present a framework of the essential elements of effective SciComm that synthesizes previous work to describe the who, why, what, and how of effectively communicating science with nonexperts. We applied the framework to a lesson for undergraduate biology students and assessed student outcomes. The lesson uses an introduction, assignment sheet, and worksheet to guide students through planning, producing, and describing their SciComm assignment. We assessed the outcomes of the lesson by quizzing students on their knowledge of SciComm and asking about their perceptions of SciComm and the lesson. Students performed well but focused some of their responses on what they were assigned in the lesson instead of what was best for effective SciComm. Moreover, students perceived the lesson positively. This work can be used by practitioners and researchers to understand how to engage students in the important scientific practice of SciComm.

Key Words: *science communication; SciComm; undergraduate; introductory biology.*

○ Introduction

Around the world, having scientists communicate science with nonscientific audiences (herein abbreviated as SciComm) is vital. The public benefits by learning about scientific advances that may influence their public policy and personal decisions, such as childhood vaccinations, environmental policy, and the support of scientific research. Scientists also benefit from communicating with nonexperts by learning about societal problems in need of evidence-based solutions. Scientists are being asked, by their institutions, scientific communities, and funding agencies, to communicate their science with nonexperts (European Commission, 2002; Leshner, 2007; Jia & Liu, 2014). Additionally, scientists view themselves as playing an important role in societal decision making (Besley & Nisbet, 2013), and most scientists communicate with the public about science in some way (Rainie et al., 2015).

SciComm is not typically part of scientific training (Brownell et al., 2013b). Expert scientists can learn the principles and gain experience through programs such as “The Art of Science Communication,” by the American Society for Biochemistry and Molecular Biology; the Center for Public Engagement with Science and Technology, by AAAS; the Alan Alda Center for Communicating Science, at Stony Brook University; and the trainings, leadership programs, and other support offered by COMPASS (www.compassscicomm.org). While science students are required to engage in SciComm (AAAS, 2011; National Research Council, 2012; Clemmons et al., 2020), a different approach is needed to train novice scientists, such as undergraduate students, in SciComm.

In many biology programs, there are few opportunities for students to engage in SciComm. Published curricula include courses dedicated to SciComm (e.g., Edmondston et al., 2010a, 2010b; Brownell et al., 2013a) and modules set within courses (e.g., Yeoman et al., 2011; Mercer-Mapstone & Kuchel, 2016). Additionally, individual instructors may develop their own assignments to engage students in SciComm (e.g., Bergan-Roller et al., 2018). Despite these efforts, there remains a lack of an organized, generalizable framework that can be widely applied across different settings and contexts to engage students in effective science communication. Here, we describe our efforts to define such a framework.

○ Theoretical Framework

The framework is grounded in evidence-based practices and principles of science communication (National Academies of Sciences, Engineering, and Medicine, 2017). One key of effective SciComm is to avoid the “deficit model,” which presumes that irrational and inaccurate beliefs about science derive from deficits in scientific knowledge and that more information will result in more

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Table 1. Framework of essential elements for effective science communication (EEES), synthesized from Mercer-Mapstone and Kuchel (2017) and Besley et al. (2018). Terms in bold represent category labels that are referenced in the text.

Strategic Category	Essential Elements for Effective SciComm
1. Who	Identify and understand a suitable target **audience**.
	Consider the levels of **prior knowledge** in the target audience.
2. Why	Identify the **purpose** and intended outcome of the communication.
	Objectives: • Increase awareness and knowledge • Boost interest and excitement • Listen and demonstrate openness • Convey competence • Reframe issues • Convey shared values • Convey warmth and respect
	Understand the underlying **theories** leading to the development of science communication and why science communication is important.
3. What	Separate essential from nonessential factual **content** in a context that is relevant to the target audience.
	Consider the social, political, and cultural **context** of the scientific information.
4. How	Encourage a two-way **dialogue** with the audience.
	Promote audience **engagement** with the science.
	Use **language** that is appropriate for the target audience.
	Use a suitable **mode** and **platform** to communicate with the target audience.
	Use **stylistic** elements appropriate for the mode of communication (such as humor, anecdotes, analogy, metaphors, rhetoric, imagery, narratives, storytelling).
	Appeal to the senses.

scientifically accurate beliefs and evidence-based decisions (Sturgis & Allum, 2004). Instead, communicators should use a "science in society" model, which emphasizes the value of meaningful bidirectional communications between experts and nonexperts (Davies, 2008). To achieve the science in society model, communicators must strategically address a number of elements.

In the literature, there are frameworks that make contributions to defining the elements of effective SciComm in specific contexts. For example, Mercer-Mapstone and Kuchel (2017) offer a framework of SciComm skills specific to undergraduate science students. Additionally, Besley et al. (2018) define important SciComm objectives. Below, we describe these influential frameworks and indicate how we used them to create a framework that can be applied across various settings and contexts to engage students in effective science communication.

Mercer-Mapstone and Kuchel (2017) describe 12 skills that undergraduate science students should exercise when communicating science with nonscientific audiences. Briefly, from a thorough literature review in the fields of communication, education, science, and science communication, a list of skills for effective science communication was developed. Then the Delphi method was used, which presented the list to experts in these fields who evaluated and commented on the skills. In the next step, the researchers revised the list of skills and had the same experts rank the skills into its final form. Presented as part of Table 1 (bolded terms and associated descriptions), the list of skills includes considering the audience, defining intended outcomes, realizing the context of the scientific content, and suggesting appropriate avenues for communicating with the audience.

We expanded the *purpose* element of Mercer-Mapstone and Kuchel's (2017) skills with the work of Besley and colleagues, who have worked extensively with science communicators (Besley & Tanner, 2011), expert scientists who engage in SciComm (Dudo & Besley, 2016; Yuan et al., 2017; Besley et al., 2018), and science communication trainers (Besley et al., 2016) to develop a set of recommended science communication objectives. They present their work and its implications on the website of the Strategic Science Communication Project (http://strategicsciencecommunication.com). There, Besley and colleagues describe the importance of defining and pursuing diverse communication objectives to achieve effective SciComm, and they provide recommendations on how to achieve those objectives. The science communication objectives are included in Table 1. These objectives support long-term goals of empowering the public to make better personal and policy-related decisions.

We combined, adapted, and organized the two aforementioned frameworks into a single framework (Bergan-Roller et al., 2018) that defines the essential elements of effective SciComm (abbreviated as the EEES framework; Table 1). We collapsed stylistic skills with narratives and storytelling into a single element (style). Additionally, we reintroduced the element of appeal, which was originally omitted from the skills list because it is important for all communication, not just science communication. We included appeal in order to have a more comprehensive framework and because the appeal element can help students engage their audience with the science. Further, we organized the elements into strategic categories based on the logic of storytelling: who, why, what, and how.

○ Methods

We developed a SciComm lesson centered on the EEES framework and implemented it in an introductory biology lab. Additionally, we assessed the outcomes of the lesson. All of the work described here was conducted with prior approval by the Northern Illinois University institutional review board (protocol no. HS17-0259).

Study Context

We conducted this study at a four-year, doctorate-granting university in the midwestern United States with students in an introductory cell biology lab. The course is required for biology and related majors (e.g., health sciences). Graduate teaching assistants (GTAs) implemented the lesson in sections of ≤18 students during the fall 2018 and spring 2019 semesters. In both semesters, all students enrolled in the course were given the option to participate in the study. In 2018, 80 of 135 students (59%) consented, 71 of whom completed the entire lesson. In 2019, 61 of 89 students (66%) consented, 51 of whom completed the entire lesson.

SciComm Lesson

Students worked in pairs to plan, produce, and describe a product that communicated science with nonexperts. The researchers worked with the course coordinator and GTAs to give students materials to facilitate the lesson, including an introduction, assignment sheet, and worksheet (provided in the Supplemental Material available with the online version of this article). The introduction provided students with background information on why science should be communicated with nonexperts and how to do so effectively. The introduction also detailed the EEES framework, including questions to help students brainstorm ways to address each element. The assignment sheet explained the logistics and constraints of the assignment. The lesson is flexible in the number of elements the instructor assigns and how the elements are constrained. Here, students were instructed to create a specific SciComm product, within the broad topic of "macromolecules," that involved the elements of the EEES framework. The assigned mode was a brief video (in 2018) or an infographic (in 2019). Changing the mode allowed the instructors to try out different versions of the flexible lesson to see which they liked best for future implementations. Additionally, the assignment sheet provided students with the rubrics that would be used to evaluate their projects. The worksheet tasked students to describe how they addressed each of the elements in their SciComm and why they choose this approach. Both the SciComm project and worksheet were due two weeks after the assignment was introduced in class.

Assessment

We assessed students by asking questions on (1) science communication in closed-response formats (referred to as quiz questions) and (2) their perceptions of the unit with Likert and open-response questions (referred to as perception questions). Quiz questions were composed of 12 multiple-choice and two multiple-select formats. Quiz questions are a mix of Bloom's level 1 (remembering) and level 3 (applying) (Crowe et al., 2008). The assessment is available in the Supplemental Material (File S2, which includes annotations for the Bloom's level of each question; answers to the quiz questions are available upon request). The assessment was given online, made available the week their SciComm projects and worksheets were due, and was open for one week. Students had to complete the assessment in order for their projects and worksheets to be graded. The assessment was developed with the expertise of the researchers and the instructional team to help evaluate this lesson; this, along with building the assessment from the literature-based framework, established a degree of content validity. However, because it was not meant to be a broadly applicable measure of science communication knowledge or skill, we did not pursue further instrument validity measures.

Analysis

We scored quiz questions for correctness and examined response frequency. For multiple-select questions, students had to select all correct options and no incorrect options for their response to be counted as correct. All values are reported as means ($\pm$ SD). Likert questions ranged from "strongly disagree" to "strongly agree" on a five-point scale. We analyzed the open-response question using emergent thematic content analysis (Braun & Clarke, 2006). Two authors (J.W. and H.B.-R.) coded all of the data independently and initially agreed on 94% of responses. We discussed the disparate codes until reaching agreement. We analyzed and present the results for the two semesters separately in case the different assigned modes (video or infographic) affected the outcomes, although they did not seem to. All names provided are pseudonyms.

○ Results

SciComm Quiz

Responses were similar between the two semesters (Table 2). Students correctly answered, on average, 66% (9.2 $\pm$ 6.7) and 65% (9.1 $\pm$ 6.7) of the 14 quiz questions in 2018 and 2019, respectively. Students answered the two types of Bloom's questions (knowing and applying) similarly. Students had the most difficulty with multiple-select questions.

Three questions assessed students' knowledge about *why* to communicate science. Almost every student (>98%) correctly identified the importance of SciComm (question 4). However, when asked to identify the important objectives, most failed to identify all

Table 2. Summary of student responses to the SciComm quiz as the percentage of students who answered each question correctly in two semesters. Questions are aligned with the framework categories and elements and annotated for Bloom's level (BL). Asterisks indicate multiple-select questions.

Category	Element	Question No.	Question Prompt Bloom's level	Fall 2018 (*n* = 71)	Spring 2019 (*n* = 51)
Why	Theory	4	It is important that science is communicated with the general public (i.e., nonscientists). BL1	100% (71)	98% (50)
	Purpose	1*	What can be important goals when communicating science to the general public? (Select all that apply) BL1	1% (1)	4% (2)
		5	Which of the following is the LEAST important goal to strive for when planning to communicate science with the general public? BL1	11% (8)	6% (3)
Who	Audience	9	You want to share your knowledge about the effectiveness of vaccines. Who would be the MOST appropriate audience for this presentation? BL3	94% (67)	92% (47)
	Prior Knowledge	10	When planning to communicate science with the general public, you should . . . BL3	93% (66)	92% (47)
What	Content	6	When doing SciComm on how carbohydrates are stored and accessed in the liver of mammals, which of the following would be the LEAST pertinent information to include in some way? BL3	66% (47)	76% (39)
How	Engagement	2	Which of the following would be the best way to engage young children in a presentation on DNA? BL3	69% (49)	73% (37)
		14	Which of the following is the best example of an audience engaging with science? BL3	48% (34)	39% (20)
	Language	8	Which of the following series of words would be the MOST appropriate when communicating science with the general public? BL3	90% (64)	88% (45)
		7*	Which of the following could be considered jargon in a presentation about carbohydrates? (Select all that apply) BL3	14% (10)	20% (10)
	Mode and Platform	11	You've been assigned to communicate science with the general public. Your goal is to listen and demonstrate openness. Which mode and platform would likely be the MOST effective? BL3	55% (39)	45% (23)
	Dialogue	13	Which of the following is the MOST effective way to communicate science with the general public? BL1	69% (49)	86% (44)
	Style	3	Which of the following is the LEAST effective way to communicate science with the general public? BL1	85% (60)	92% (47)
		12	You've been assigned to communicate science with bankers from the general public. Your goal is to convey shared values. Which style would likely be the MOST effective? BL3	79% (56)	69% (35)

of the seven correct responses (question 1). The single distractor (i.e., showing a lot of information) was chosen by only a small proportion of students (Figure 1). Students tended to choose increasing awareness and knowledge (>94%) and boosting interest and excitement (>90%) as important goals of SciComm (Figure 1); notably, these were the two SciComm objectives assigned to the students in the lesson. When asked to identify the least important goal of SciComm, only a small proportion of students chose the correct response (question 5; Figure 2).

Two questions assessed knowledge of *whom* to communicate with (i.e., the audience) and their prior knowledge. Most students (>92%) correctly identified parents as the most appropriate

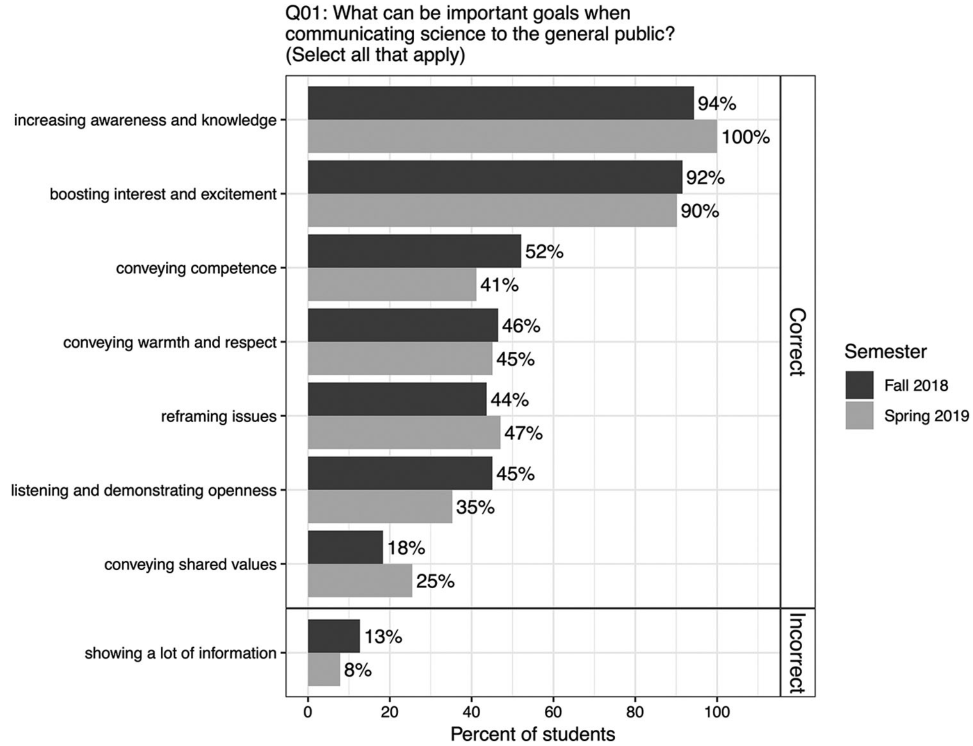

Figure 1. Percentage of students who selected each multiple-select option of important SciComm objectives. Of the eight options, the top seven are correct and the last option is the distractor.

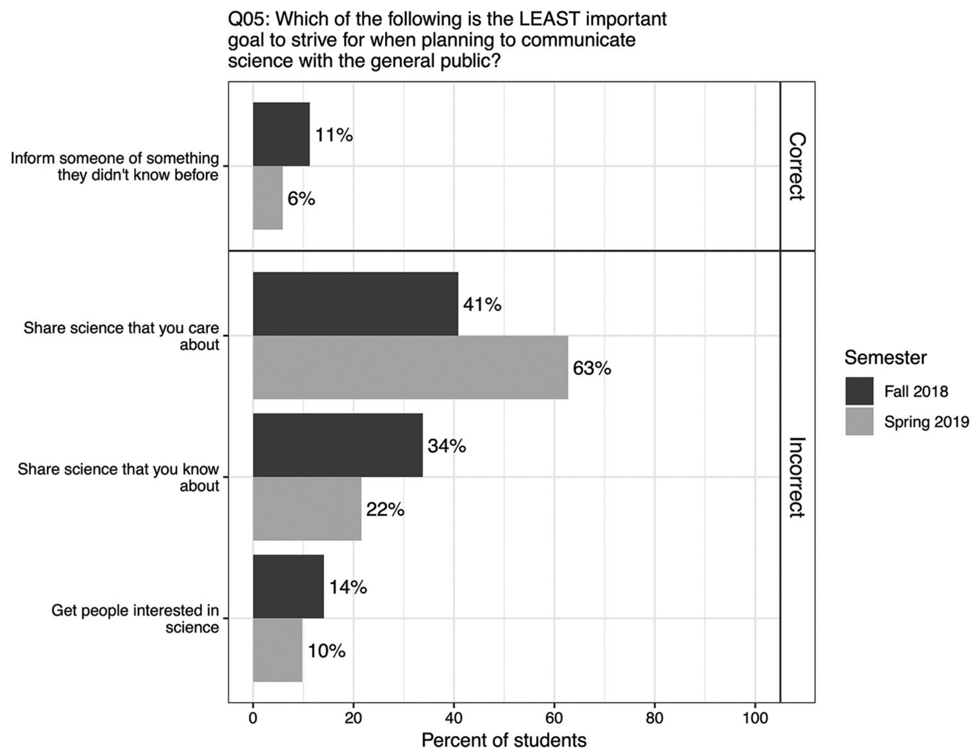

Figure 2. Percentage of students who selected each multiple-choice option for the least important SciComm objective. The top choice is correct and the bottom three choices are distractors.

audience for information on vaccines (question 9). Similarly, most students (>92%) correctly identified the importance of researching the audience's interests and prior knowledge when preparing a SciComm (question 10). On the question designed to assess knowledge of communicating focused content, most students (>66%) correctly identified the least relevant content (question 6).

Eight questions assessed knowledge of *how* to effectively communicate with nonexperts; two of those questions assessed

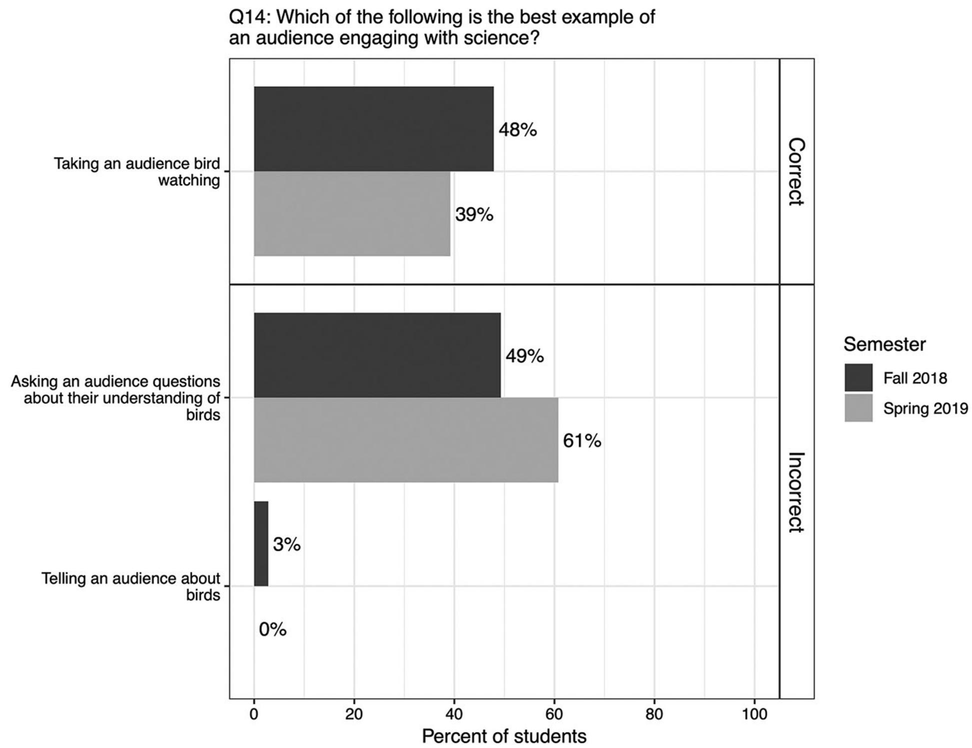

Figure 3. Percentage of students who selected each multiple-choice option for how to engage the audience with science. The top choice is correct and the bottom two choices are distractors.

knowledge of how to engage the audience with the science. Most students (>69%) correctly identified how best to engage with young children (question 2). However, fewer than half of students correctly chose the best way to engage their audience with the science by incorrectly choosing to ask their audience questions about birds instead of (correctly) taking them bird watching (question 14; Figure 3).

Two questions assessed knowledge of what language to use when communicating with the audience. Most students (>88%) correctly identified scientific jargon (question 8). However, when asked to identify all of the jargon that should be avoided in a presentation, some students (<33%) incorrectly selected non-jargon terms like *blood* and *sugar* (question 7). Approximately half of students correctly selected a small gathering at a coffee shop as the best mode and platform for listening and demonstrating openness while a significant portion also chose posting to social media (question 11; Figure 4). Comparing the two semesters, more students incorrectly chose the mode they were assigned, with more 2018 students choosing the video and more 2019 students choosing the infographic despite the context of the question (Figure 4). Most students (>69%) correctly identified the value of dialogue in communicating science with the general public (question 13).

The two remaining questions assessed knowledge of style. Most students (>85%) correctly identified presenting a lot of data as the least effective way to communicate science with nonexperts (question 3). Similarly, most students (>69%) correctly identified the best way to demonstrate shared values with a general audience (question 12).

Perceptions

Perceptions of the unit were consistently positive, with slightly higher rates of positive responses from 2019 (Figure 5). Most students agreed or strongly agreed that the lesson materials were helpful (Figure 5A), that the lesson improved their ability to effectively communicate science with the public (Figure 5B), and that the lesson improved their understanding of the assigned content (Figure 5C).

Students provided a variety of input when asked to describe one thing that they would change about the lesson. Students suggested changes to the lesson as a whole, the constraints of the framework elements, and/or the logistics of the assignment (Table 3). The most common response was that nothing needed to be changed (2018: 19%; 2019: 27%), which was commonly accompanied by an endorsement of the lesson (8%, 16%). For example, Naveen said that he would change "nothing" and "thought it was fairly simple to do and informative." However, a few students ($n_{2018} = 7$, $n_{2019} = 1$) thought the whole lesson should be discarded.

Regarding suggested changes to the framework elements, some students wanted to change their platform for sharing their SciComm with just the GTA to actually presenting to the public (12%). For example, Charlotte, a student in the spring 2019 semester, said:

> I would have people actually use their presentations instead of just submitting it to the teacher. You're not really communicating if only the teacher gets the information. It would be better if there were two options: one to post it on YouTube so that people could actually use it, or for there to be some type of event in which students, elderly, or middle schools were able to come and listen to our presentations.

As for changing the content, some students wanted to be directed to specific information to communicate, instead of having

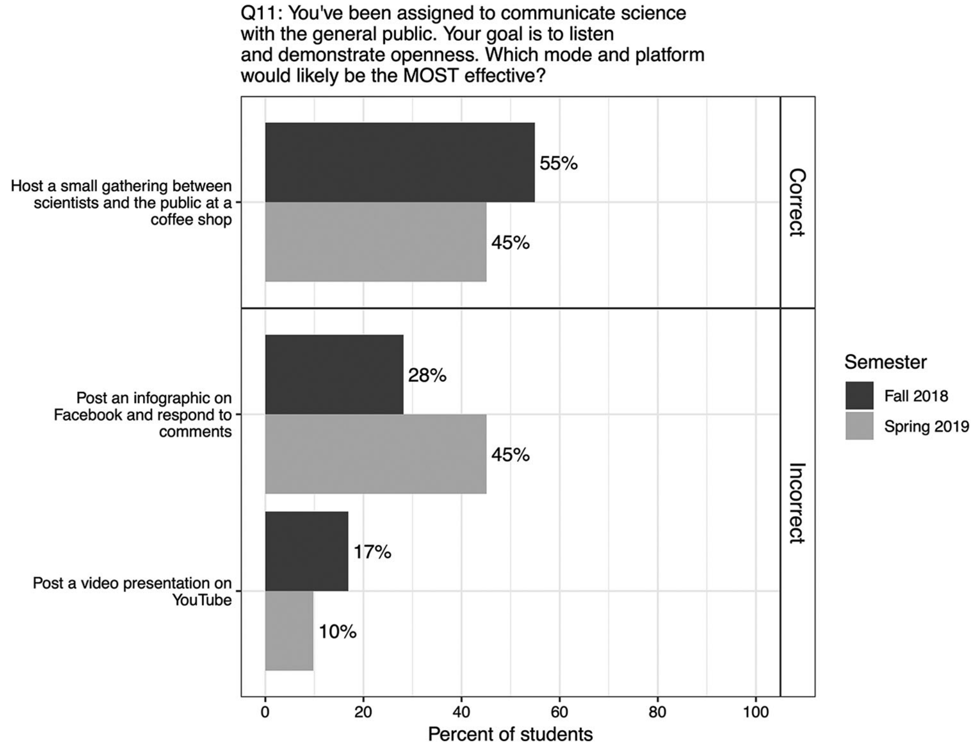

Figure 4. Percentage of students who selected each multiple-choice option for an appropriate mode and platform given a SciComm objective. The top choice is correct and the bottom two choices are distractors.

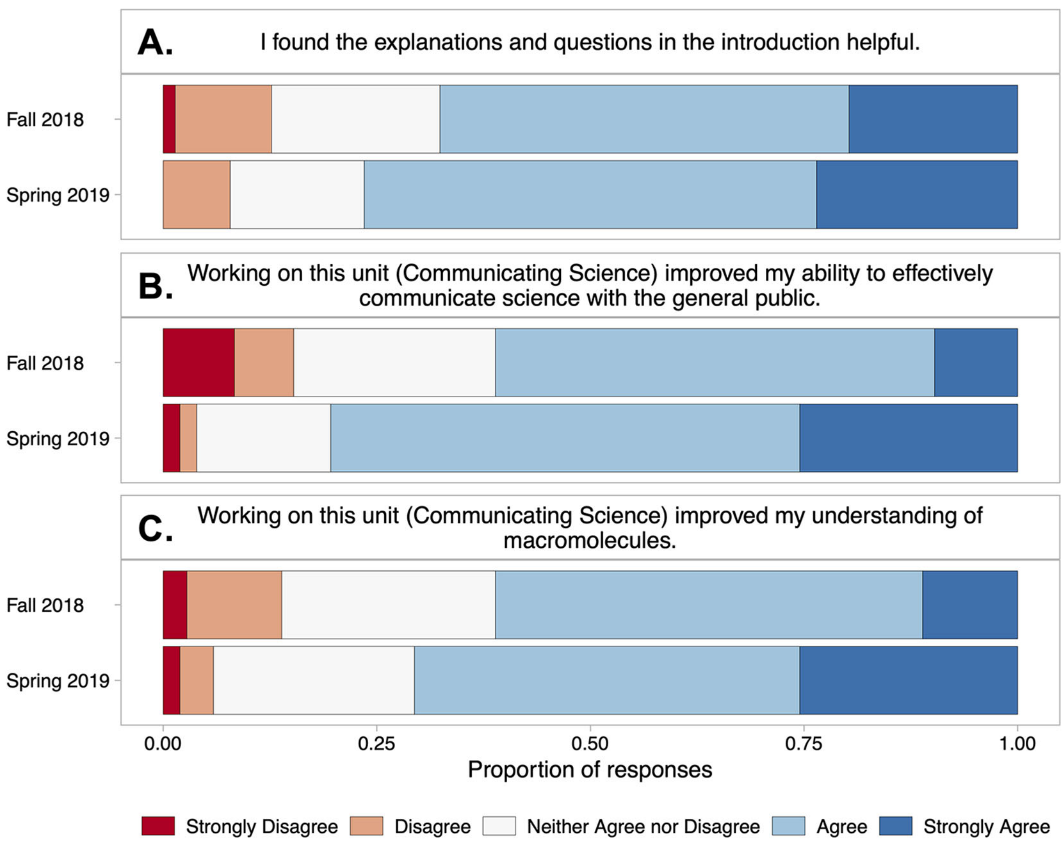

Figure 5. Summary of student responses to Likert-style perception questions as proportion of positive (blues), neutral (white), or negative (red/orange) in two semesters. Questions asked students to rate their agreement on (**A**) whether the introduction materials were helpful, (**B**) whether the lesson improved their SciComm skills, and (**C**) whether the lesson improved their knowledge of biological content.

Table 3. **Summary of responses to the open-response prompt asking for feedback on one thing they would like changed about the SciComm lesson. Values represent the percentage (and numbers in parentheses) of students who described a change that aligned with each theme. Each response could have multiple parts that fit different themes; therefore, columns may not add up to 100%.**

Themes	Fall 2018 (n = 71)	Spring 2019 (n = 51)	Subthemes
Whole	38% (27)	45% (23)	Keep the lesson as is; endorse; discard
Framework element	35% (25)	35% (18)	Change the content, mode, audience, platform
Logistics	23% (16)	18% (9)	More time, work alone

to decide for themselves given a broad topic, and others wanted to be able to choose any topic and not be constrained at all.

Logistical changes included giving more than two weeks to complete the assignment and working alone instead of in pairs. A portion of the responses either did not fit one of the major themes (<10%) or were unclear or irrelevant (≤15%).

○ Discussion

As described above, we implemented a lesson based on the EEES framework in an introductory biology lab over two semesters. While the two implementations varied slightly in the mode of communication assigned (video or infographic), the resulting student outcomes were similar. After engaging in the lesson, students seemed to understand and were able to apply many of the essential elements of effective SciComm.

However, students did not identify the importance of the variety of communication objectives; instead they focused on increasing the knowledge of their audience. This is similar to how scientists prioritize knowledge-sharing objectives over others such as conveying shared values or competence (Besley et al., 2018). Another difficulty students had was that they seemed to focus on the elements and constraints of their assignment instead of trying to understand SciComm broadly. For example, students most often identified the two objectives they were assigned as important over the other five correct and one incorrect response options (Figure 1). Similarly, more students, given a specific objective, chose the mode they were assigned rather than the most effective mode. Together, this suggests that engaging students with specific elements of SciComm focuses their attention on those elements but does not necessarily enhance their understanding of effective choices for the elements.

Additionally, students seemed to have difficulty identifying how to engage an audience. Instead of choosing bird watching, most students picked a question-and-answer session as the most engaging. As educators, we recognize the importance of engagement when trying to increase the knowledge of our audience (i.e., students in the classroom; Freeman et al., 2014). Instead, it seems as if these students thought that engagement should look like it does in most of their courses, with traditional lecture-like presentations and a few question-and-answer opportunities (Stains et al., 2018).

While our assessment provides insight into students' understanding of effective SciComm in this context, it is not a fully validated instrument. Therefore, the generalizability of these results is limited. However, similar results were seen between the two semesters, which suggests that the instrument has potential. Future work should include the development of a more robust instrument, with evidence of validity and reliability, that assesses students' SciComm knowledge and skills.

Regardless of the knowledge and skills students gained from the lesson, our primary goal was to *engage* students with the authentic scientific practice of SciComm. Future work may investigate how this lesson works in concert with other authentic science experiences, such as undergraduate research experiences and course-based undergraduate research experiences (CUREs).

Student perceptions provide valuable insight as to how an activity can be improved in future implementations. Here, students reviewed the lesson positively, indicating that the self-contained instructions were adequate and that they had learned biological content and science skills in the lesson. The later implementation (2019) received slightly more positive reviews. This could be due to a logistically easier assignment of creating an infographic (versus a video in 2018) and/or because the same GTAs led the lesson for both implementations and perhaps were more adept the second time. However, the fidelity of lesson implementation was not assessed or compared between semesters.

Students provided a variety of suggested changes to the lesson. We incorporated some applicable changes (e.g., provide an example) in revised versions of the lesson. Future work will investigate how individual changes (e.g., un-prescribed audience) may influence outcomes (e.g., the SciComm students produce) and perceptions. This follow-up work will inform how the lesson can be optimized and adapted to fit a variety of contexts.

○ Conclusion

SciComm is an important scientific skill with which undergraduate students should engage. We developed a literature-based framework of the essential elements of effective SciComm and applied the framework to develop a lesson for undergraduate biology students in an introductory lab course. The flexible lesson guides students to plan, produce, and describe their SciComm. We assessed the outcomes of the lesson by quizzing students on their knowledge and application of the SciComm elements and asking about their perceptions. Overall, students performed well but focused some of their responses on what they were assigned in the lesson instead of what was best for effective SciComm. Moreover, students perceived the lesson positively and made minor suggestions for changing it.

This work has applications for both practitioners and researchers. It will help instructors facilitate student engagement in a core scientific practice (SciComm) through implementation of a framework grounded in evidence and theory. Additionally, the framework could be used to generate alternative lessons. For researchers, the EEES framework and assessment provides tools for assessing students on their development of this core competency. This work with novice scientists could help inform groups working to train more experienced scientists in SciComm.

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