Introductory Biology Students Communicating Science

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Abstract

Communicating science to a general audience (SciComm) is an important scientific skill widely practiced by scientists. It is important that scientists do SciComm as it can impact decision making by the public and inform 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 a lack 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 to a public audience. We applied the framework to a lesson for undergraduate biology and assessed its effectiveness. The lesson uses an introduction, assignment sheet, and worksheet to guide students through planning, producing, and describing their SciComm. We assessed the effectiveness of the lesson by quizzing students on their knowledge of SciComm and asking about their perceptions. 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 important scientific practice.

Introduction

Having students engage in the same practices as scientists is important to foster future generations of scientists and develop a scientifically literate society. Seminal documents have defined the scientific practices in which students at the primary, secondary (National Research Council 2012) and post-secondary levels (e.g., American Association for the Advancement of Science (AAAS), 2011) should engage; one of which is science communication. Communicating science can take on many forms and is generally classified as communicating either with a scientific or general, non-scientific audience such as the public. While both are important skills for students (Clemmons et al. 2019), our current project focuses on the latter category: communicating science with a general, non-scientific audience (herein abbreviated as SciComm).

Around the world, fostering high-quality SciComm by scientists is increasingly vital as scientific communities call on scientists to communicate more frequently with the general public and across a range of formats and channels (European Commission 2002; Jia and Liu 2014; Leshner 2007). Additionally, scientists view themselves as having an important role to play in societal decision-making (Besley and Nisbet 2013) and most communicate with the public about science in some way (Rainie, Funk, and Anderson 2015).

Scientists who do seek out SciComm professional development commonly learn the principles and gain experience through workshops and programs offered through professional societies (e.g., the Art of Science Communication by American Society for Biochemistry and Molecular Biology, Center for Public Engagement with Science & Technology by AAAS) and other organizations (e.g., Alan Alda Center for Communicating Science, COMPASS).

For students, specifically students in biology-related programs, there are fewer wide-spread opportunities to engage in SciComm. A few have published on SciComm curricula in this setting and include whole courses dedicated to SciComm (e.g., Brownell, Price, & Steinman, 2013; Edmondston, Dawson, & Schibeci, 2010a, 2010b) or modules set within courses (e.g., Yeoman, James, & Bowater, 2011; Mercer-Mapstone & Kuchel, 2016). Additionally, individual instructors may develop their own assignments that engage science students in SciComm. 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 and principles science communication (National Academies of Sciences, Engineering 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 scientifically accurate beliefs and evidence-based decisions (Sturgis and Allum 2004). Instead, communicators should use a “science in society” model, which highlights the value of meaningful bidirectional communications between experts and non-experts (Davies 2008). To achieve the science in society model, communicators need to strategically address a number of elements.

In the literature, there are frameworks that make contributions in 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 and colleagues have defined important SciComm objectives. Below, we describe these influential frameworks and indicate how we combined, adapted, and organized them into a generalizable framework that can be widely applied across different 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 to a general audience. Briefly, the list of skills was first developed with a thorough literature review for effective science communication in the fields science, communication, education, and science communication. Then the Delphi method was used, which presented the list to experts in these fields who evaluated, revised, and ranked 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 and their prior knowledge, the context of focused scientific content, and the theoretical underpinnings of SciComm. It directs students to use language and style that is appropriate for the audience and a mode and platform to effectively reach the audience. It encourages students to engage the audience with the science and have an open two-way dialogue. Finally, the framework directs students to identify the purpose and intended outcomes of the communication.

We expanded the purpose element of Mercer-Mapstone and Kuchel's (2017) skills with the work of Besley and colleagues. Through their extensive work with science communicators (Besley and Tanner 2011), scientists who engage in SciComm (Dudo et al. 2016; Yuan et al. 2017; Besley, Dudo, and Yuan 2018), and science communication trainers (Besley et al. 2016), they have developed a set of recommended science communication objectives. They present their synthesized work and its implications at http://strategicsciencecommunication.com/. There, Besley and colleagues describe the importance of defining and pursuing diverse communication objectives to achieve effective SciComm as well as provide recommendations on how to achieve those objectives. The science communication objectives are to increase awareness and knowledge, boost interest and excitement, listen and demonstrate openness, convey competence, reframe issues, convey shared values, convey warmth and respect, which support the long-term goals of science communication such as strengthening STEM workface and empowering personal decision-making.

We combined, adapted, and organized the two aforementioned frameworks into a single framework (Bergan-Roller et al. 2018) that defines the <u>e</u>ssential <u>e</u>lements of <u>e</u>ffective <u>S</u>ciComm (abbreviated as the EEES framework, Table 1). Major adaptations include collapsing stylistic skills with narratives and storytelling into a single element (style). Additionally, we re-introduced the element of appeal, which was originally omitted from the skills list because it is important for all communication, not just science communication. We include appeal in order to have a more comprehensive framework and thought it would help students to engage their audience with the science. Further, we organized and ordered all of the elements into strategic categories based on the logic of storytelling–who, why, what, and how.

We applied the EEES framework to develop a SciComm lesson for undergraduate introductory biology lab. The lesson has students create and describe some SciComm based on the principle that students need to construct their own understanding by engaging with content and skills over being lectured to (Freeman, Eddy, McDonough, Smith, Okoroafor, et al. 2014). Additionally, we assessed the effectiveness of the lesson by examining student performance on a SciComm quiz and surveying their perceptions of the lesson.

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

Strategic Category	**Essential Elements for Effective SciComm** adapted from Mercer-Mapstone and Kuchel, 2017
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 from Besley et al., 2018 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 it 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.

Methods

To demonstrate how the framework can be applied, we developed a SciComm lesson centered on the EEES framework and implemented it in an introductory biology lab. Additionally, we assessed the effectiveness of the lesson by assessing the students' ability to apply and identify the elements of effective SciComm in a closed-response quiz and asked for their perceptions of the lesson with a survey. All of the work described here was conducted with prior approved by the institutional review board protocol #HS17-0259.

Study context

The study was conducted at a large four-year, doctoral-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 up to 18 students during Fall 2018 and Spring 2019. In both semesters, all students enrolled in the course were given the option to participate in the study. In Fall 2018, 80 of the 135 students (59%) consented, of which 71 completed the entire lesson. In Spring 2019, 61 of the 89 students (66%) consented, of which 51 completed the entire lesson. Only work from students who consented and completed the entire lesson was included in this research.

SciComm lesson

Students worked in pairs to plan, produce, and describe a product that communicated science with the public. Students were given materials to help facilitate their learning including an introduction, assignment sheet, and worksheet. The introduction provided students with background information on why science should be communicated with the public and how to be effective. The introduction also presented the EEES framework and gave insight on each element including questions to help students brainstorm ways to address the elements. The assignment sheet instructed students on the logistics and constraints of the assignment. Specifically, they were instructed to create a SciComm product pertaining to the topic of "macromolecules" that involved each element of the EEES framework. The assigned mode was a brief video for Fall 2018 and an infographic for Spring 2019. Additionally, the assignment sheet provided students with the rubrics on how their projects would be evaluated. The worksheet tasked students to describe how they addressed each of the elements in their SciComms and why they choose to do so. Both the SciComm project and worksheets were due two weeks after the assignment was introduced in class.

Assessment

Students were assessed three weeks after the lesson was assigned and one week after they submitted their SciComm projects and worksheets. The assessment was a survey that asked questions on (a) applying their knowledge of science communication in closed-response formats (referred to as quiz questions) and (b) their perceptions of the unit with Likert and open-response questions (referred to as perceptions questions). Quiz questions were composed of 12 multiple-choice and 2 multiple-select (i.e., "select all that apply") formats. The quiz question prompts but not response options are listed in Table 2.

Analysis

Quiz questions were scored for correctness and examined for frequencies of responses. For correctness of multiple-select questions, students had to select all correct options and no incorrect options to be counted as correct. All values are reported as mean ± one standard deviation. Likert perception questions ranged from strongly disagree to strongly agree on a five-point scale. Open-responses were analyzed using emergent thematic content analysis (Braun and Clarke 2006) and coded to consensus by two authors (J.W. and H.B-R.). All names provided are pseudonyms.

Results

SciComm knowledge

Overall, student responses were similar between the two semesters (Table 2). Students correctly answered, on average, 66% (9.2 ± 6.7) and 65% (9.1 ± 6.7) of the 14 quiz questions for Fall 2018 and Spring 2019, respectively. Students had the most difficulty with multiple-select questions.

Table 2. *Summary of student responses to SciComm quiz as the percent of students who answered each question correctly in two semesters. Questions are aligned with the framework categories and elements. *Indicates multiple-select questions.*

Category	Element	Q#	Question prompt	Fall 2018 (n = 71)	Spring 2019 (n = 51)
Why	Theory	4	It is important that science is communicated with the general public (i.e., non-scientists).	100% (71)	98% (50)
	Purpose	1*	What can be important goals when communicating science to the general public? (Select all that apply)	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?	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?	94% (67)	92% (47)
	Prior Knowledge	10	When planning to communicate science with the general public, you should...	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?	66% (47)	76% (39)

Category	Element	Q#	Question prompt	Fall 2018 (n = 71)	Spring 2019 (n = 51)
How	Engagement	2	Which of the following would be the best way to engage young children in a presentation on DNA?	69% (49)	73% (37)
		14	Which of the following is the best example of an audience engaging with science?	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?	90% (64)	88% (45)
		7*	Which of the following could be considered jargon in a presentation about carbohydrates? (Select all that apply)	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?	55% (39)	45% (23)
	Dialogue	13	Which of the following is the MOST effective way to communicate science with the general public?	69% (49)	86% (44)
	Style	3	Which of the following is the LEAST effective way to communicate science with a general public?	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?	79% (56)	69% (35)

Three questions assessed students' knowledge of the purposes and importance of SciComm. 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 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). Student responses tended to emphasize 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).

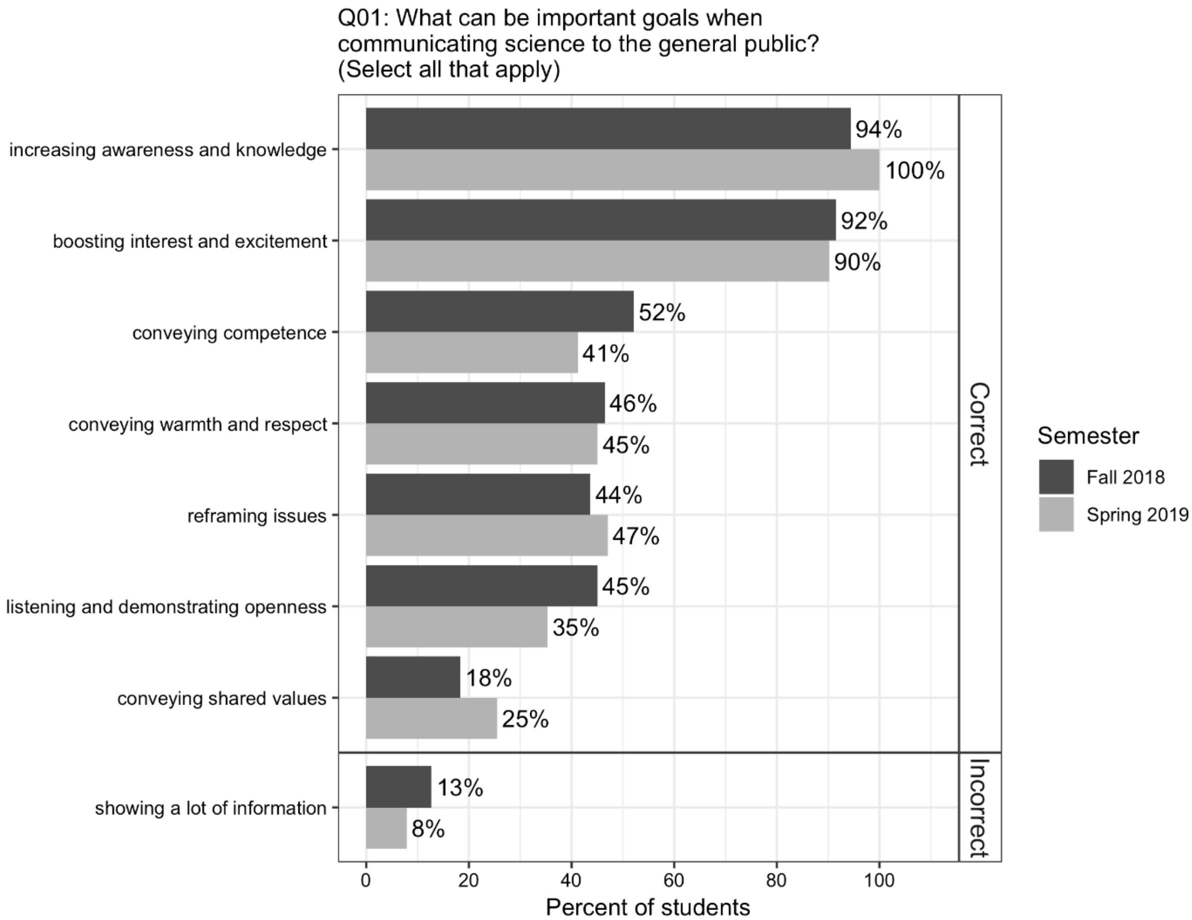

Figure 1. *Percentage of students who selected each multiple-select option of important SciComm objectives. Of the eight options, the top seven are correct and the last option was the distractor.*

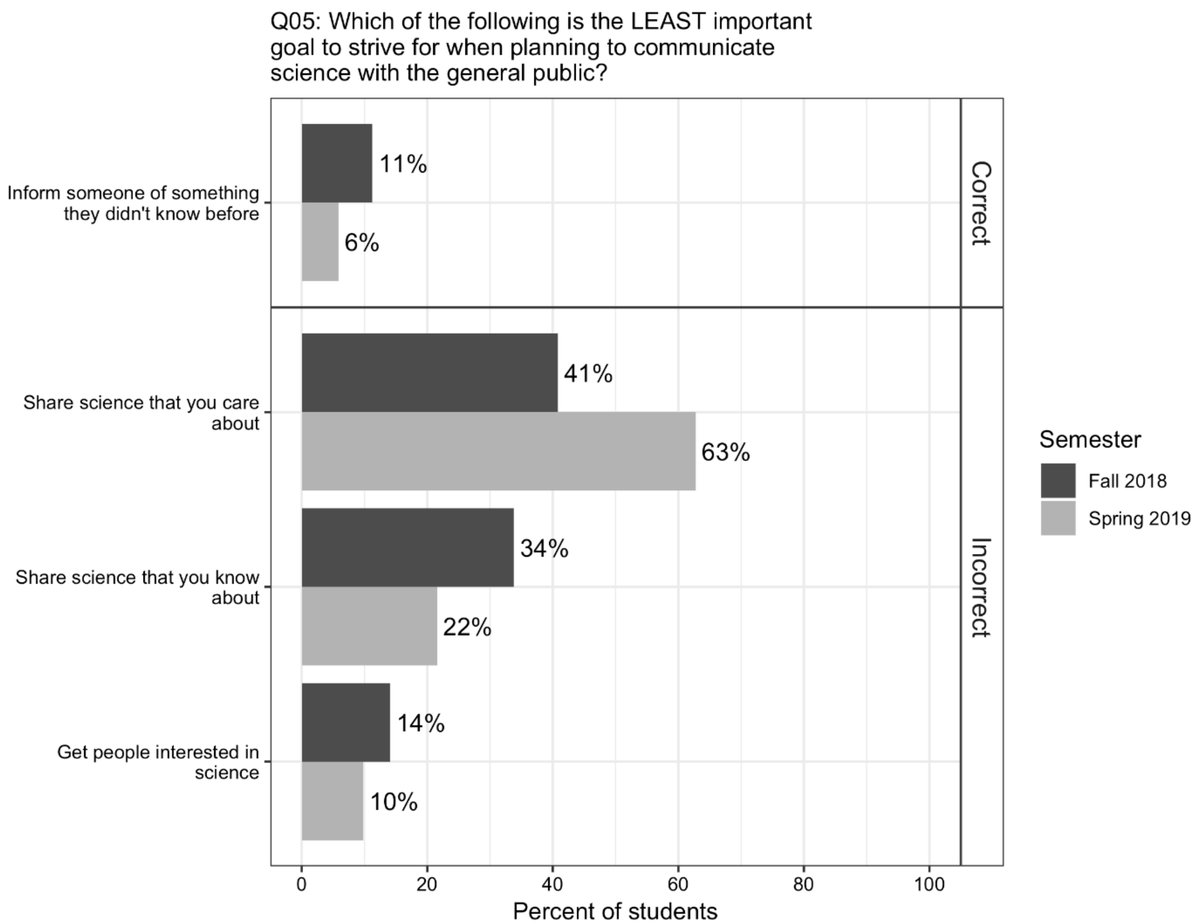

***Figure 2**. Percentage of students who selected each multiple-choice option for the least important SciComm objective. The top choice was correct and the bottom three choices distractors.*

Two questions assessed students' knowledge of *who* to communicate with (i.e., the audience) and their prior knowledge. Most students (>92%) correctly identified parents as the most appropriate 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 single question designed to assess students' knowledge of communicating focused content, most students (>66%) correctly identified the least relevant content (question 6).

Eight questions assessed students' knowledge of *how* to effectively communicate with the general public. Of those, two questions assessed students' 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 to engage their audience with the science by taking an audience bird-watching, and a slightly larger proportion of students incorrectly chose asking an audience questions about their understanding of birds (question 14, Figure 3).

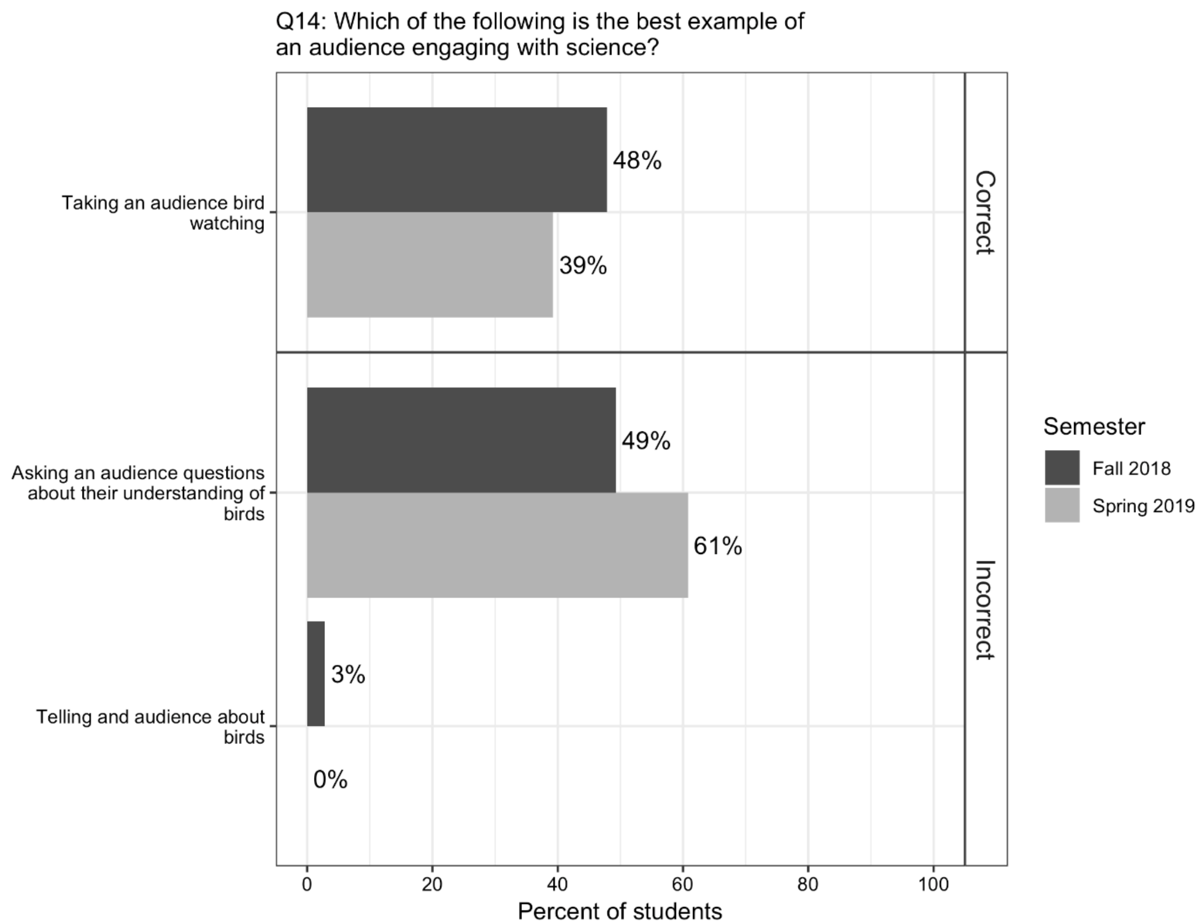

Figure 3. *Percentage of students who selected each multiple-choice option for how to engage the audience with science. The top choice was correct and the bottom two choices distractors.*

Two questions assessed students' knowledge of what language to use when communicating with their audience. Most students (>88%) correctly identified scientific jargon from a list of terms (question 8). However, when asked to select all that apply, more than half of students identified jargon that should be avoided in a presentation, some students (<33%) also 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 choose posting to social media question 11, Figure 4). Comparing between the semesters, more students incorrectly chose the mode they were assigned with more Fall 2018 students choosing the video and more Spring 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).

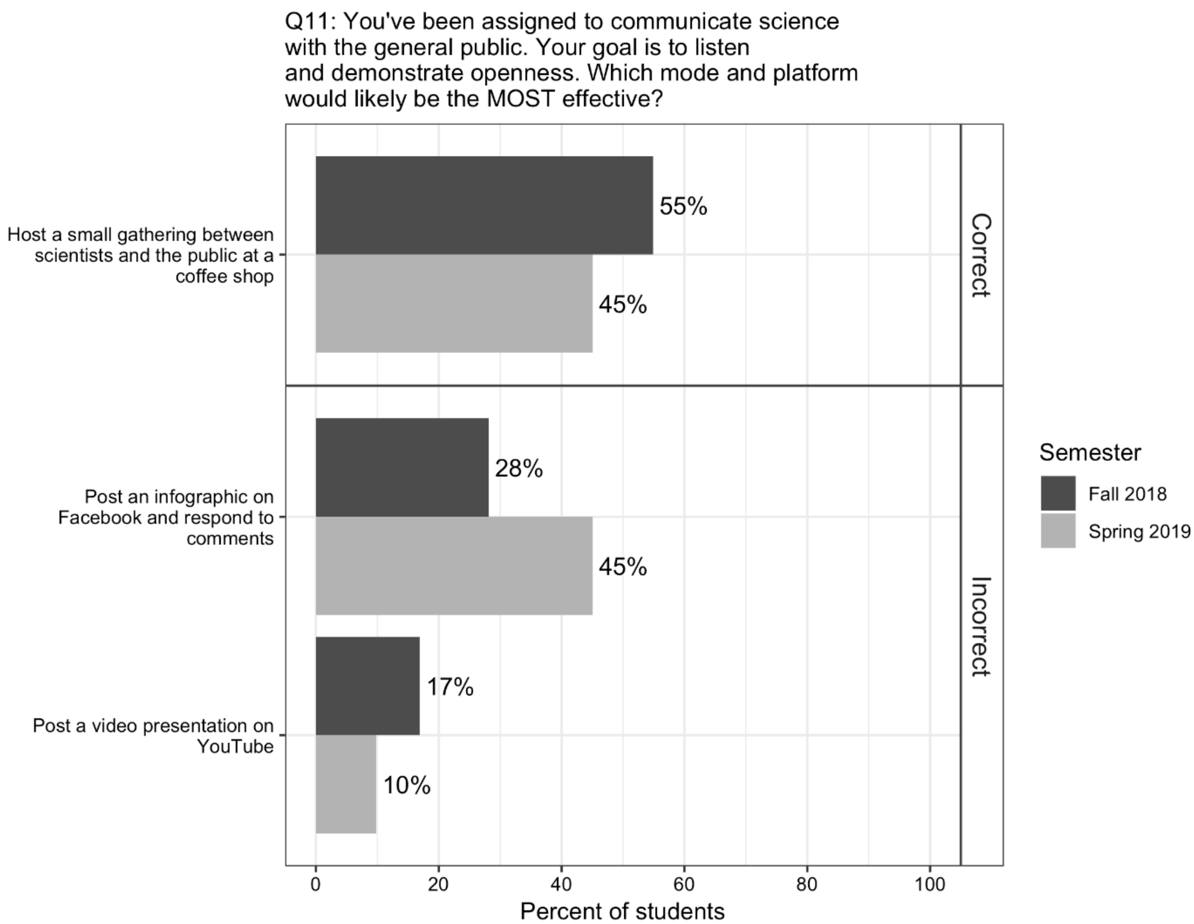

Figure 4. *Percentage of students who selected each multiple-choice option for an appropriate mode and platform given a SciComm objective. The top choice was correct and the bottom two choices distractors.*

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

Perceptions

Students' perceptions of the unit were consistently positive, with slightly higher rates of positive responses from Spring 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 (i.e., macromolecules, Figure 5C).

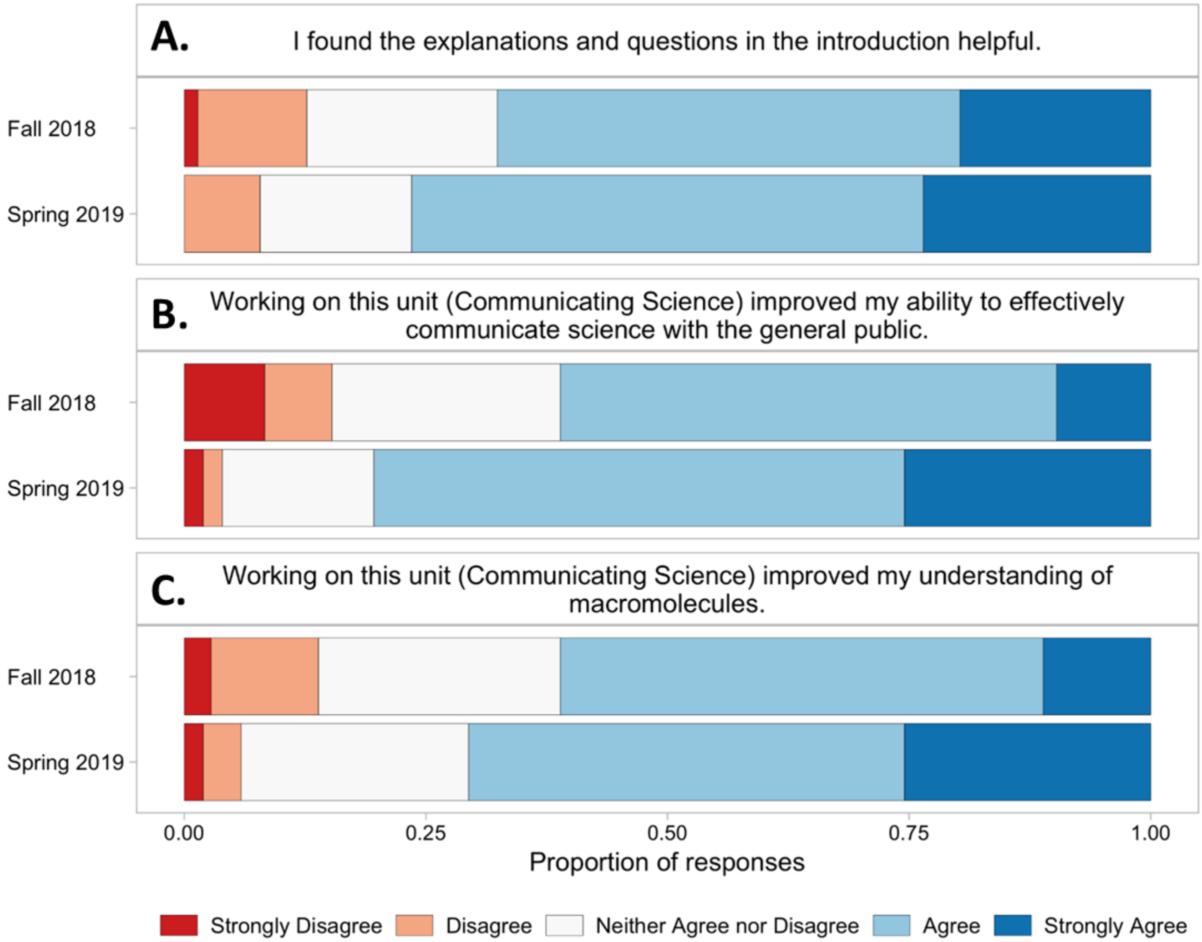

Figure 5. *Summary of student responses to Likert-style perception questions as proportion of positive (blues on the right), neutral (white), or negative (red/orange on the left) in two semesters. Questions asked students to rate their agreement on if the introduction materials were helpful (A), if the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

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

Table 3. *Summary of student responses to open response prompt asking for feedback on one thing they would like changed about the SciComm lesson. Values represent the percent (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

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 from Spring 2019 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 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 that were suggested included giving more than the 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

The EEES framework can be applied to generate lessons to engage students in effective SciComm that is guided by theory and evidence. Here, we presented a lesson based on the EEES framework that was implemented 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 students engaged in the SciComm lesson, they seem to understand most of the essential elements of effective SciComm.

Students had the most difficulty identifying all of the effective purpose objectives. Students focusing on the SciComm objective of increasing knowledge and awareness correctly is similar to how scientists prioritize science communication objectives. A survey conducted with scientists from multiple scientific societies showed that scientists still focus more on the traditional and educational objectives but less on the non-knowledge objectives (Besley, Dudo, and Yuan 2018).

In addition to increasing knowledge and awareness, most students correctly identified boosting interest and excitement about science as an important SciComm objective over the other five correct and one incorrect response options (Figure 1). These two objectives were what students were instructed to focus on in the lesson suggesting that the assigned elements of the lesson influenced students' understanding of effective SciComm. Similarly, more students chose the mode which they were assigned instead of the most effective mode given a specific objective. 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.

Another element the students had difficulty with was identifying the most engaging activity. Instead of choosing to engage their audience with the science of birding, most students picked a questions and answer session as the most engaging. We as educators recognize the importance of engagement when trying to increase knowledge of our audience, students in the classroom, with active learning (Freeman, Eddy, McDonough, Smith, Okoraofor, et al. 2014); however, students are likely less aware of this evidence. Instead, it seems like the students thought engagement should look like it does in most of their courses with traditional lecture-like presentations with a few question and answer opportunities (Stains et al. 2018).

While our assessment provides insight into students understanding of the essential element of effective SciComm, it should be noted that 2 of the 14 questions were multiple-select while the rest were multiple-choice. Specifically, students were asked to identify all of the effective purpose objectives (question 1 on purpose) and identify jargon terms (question 7 on language). Students had to select all of the correct options and none of the incorrect options for their answers to be considered correct. Question format has been shown to influence what knowledge students are able to demonstrate (Hubbard, Potts, and Couch 2017) with multiple-choice questions tending to overestimate students' understanding (Couch, Hubbard, and Brassil 2018). Here, fewer students answered the multiple select questions correctly compared to the multiple choice questions. Therefore, differences in how our students demonstrated their knowledge of the elements SciComm could have been influenced by question format instead of just differential understanding of the elements of effective SciComm. Future work should include the development of a valid and reliable instrument that assesses students' SciComm knowledge and skills with a uniform format like that of other recent assessment tools (Newman et al. 2016; Couch, Wood, and Knight 2015; Couch et al. 2019).

Regardless of the knowledge and skills students gained from the lesson, our primary goal was to engage students with an authentic scientific practice, SciComm. Engaging in scientific practices, in the context of undergraduate research experiences (UREs) and laboratory course-based UREs (CUREs), increases persistence in STEM programs (Estrada et al. 2011; Hernandez et al. 2013; Nadelson et al. 2017). SciComm may not be a traditionally regarded as what scientists do or is typically covered in undergraduate labs or research experiences. Therefore, future work will investigate if and how engaging in SciComm influences STEM retention and the psychosocial factors associated with retention.

Student perceptions are valuable in gaining insight as to how an activity can be improved and as an indication of dissemination applicability. Here, students reviewed the SciComm lesson positively indicating that the self-contained instructions were adequate and that they learned biological content and science skills. The later implementation (Spring 2019) received slightly more positive reviews. This could be due to a logistically easier assignment of creating an infographic (versus a video in Fall 2018). Another potential influence for the more positive reviews in the second implementation is that the same GTAs led the SciComm lesson for both implementations. Therefore, the more positive student reviews could be partially attributed to the GTAs being more comfortable and/or adept at leading the lesson. 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, individual projects) may influence student outcomes and perceptions. This follow-up work will inform how the lesson can be optimized or adapted to fit the context of different students, courses, instructors, and institutions.

In addition to assessing of students' skills and perceptions, future work will characterize the work students produce. Specifically, their SciComm projects and worksheets will be analyzed for what elements of the EEES students implemented, how they addressed the elements, and why they made those decisions.

Conclusion

Communicating science to a general audience (SciComm) is an important scientific skill widely practiced by scientists with which undergraduate students should engage. Unfortunately, students have few opportunities to engage in SciComm partially due to a lack 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 to a public audience. We applied the framework to develop a lesson for undergraduate biology students in an introductory lab course. The lesson uses an introduction, assignment sheet, and worksheet to guide students through planning, producing, and describing their SciComm. We assessed the effectiveness of the lesson by quizzing students on their knowledge of SciComm 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 change.

This work has utility for both practitioners and researchers. It will help instructors facilitate student engagement in a core scientific practice (science communication) through application of a framework grounded in evidence and theory. Although the example lesson is set in an undergraduate setting, the lesson could be applied throughout the biology curricula. Moreover, the framework could be used to generate alternative lessons. For researchers, the EEES framework and survey provides tools for assessing students on their development of a core competency. Broadly, this work could help inform groups working to train scientists on SciComm. This work provides an example of how students can engage in atypical yet important scientific practices which has potential for helping to develop future scientists and engaged citizens.

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