SciComm: An Oral Communication Professional Development Program for STEM Graduate Students

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Abstract

Now, more than ever, is a time when scientists and engineers must be able to create a factual and compelling account of their research. How can STEM graduate students learn to communicate complex information to a variety of audiences in a concise way? An NSF-funded STEM oral communication program, called "SciComm", was developed and implemented at a large public institution to meet this professional development need for STEM graduate students.

The SciComm program engaged a cohort of 28 STEM graduate students in bi-weekly seminar meetings during the 2017-2018 academic year. The program goals were twofold: First, to equip students with the training and experience to effectively and confidently communicate their research with a variety of audiences that a STEM professional may encounter. Second, to develop or deepen students' understanding of the diverse set of future career opportunities available to STEM PhD holders. To accomplish these goals, the program was designed with three components: 1) hands-on training seminars, 2) communication challenges putting the training into practice on video and for audiences reflective of the professions discussed in the program, and 3) mentorship by a non-program institutional STEM alumnus/a.

This paper will present the program design and research results from the first year. Using a mixed methods approach, we sought to examine the extent to which graduate students' perceptions of communication confidence and awareness of STEM career opportunities improved over the course of the program. We also aimed to measure their communication skills to different audiences and obtain feedback on the most impactful program components. Data included pre/post-surveys, focus groups, and program artifacts (e.g., reflections, videos). Quantitative data were analyzed using paired t-tests, and qualitative data were analyzed using a constant comparative approach. Results demonstrate that graduate students became more confident in their ability to communicate scientific research and significantly improved their understanding of non-industry related careers. Graduate students found the mentor interactions, creation of communication videos, and interdisciplinary of the program as the most helpful components. These results suggest that the SciComm program successfully met its goals, and points to additional program benefits that participating graduate students recognized beyond the stated learning outcomes. In our paper, we will share our research results as well as suggestions for communication program implementation at other universities.

Introduction

The ability to effectively transfer knowledge and discovery across a diverse group of constituencies is central to building a scientific workforce capable of taking on the grand challenges of our time. Divorced from sectors such as policy, business, education, and the public sphere, the impact of today's scientific trainees risks being minimized and cordoned off the very areas where they are in greatest need, and stand to have the greatest impact on society. At the core of this transfer of knowledge lies the ability to convey complex scientific information to all people – scientists and non-scientists alike – through credible and compelling communications.

Importance of communication for graduate students

Effective communication is a skillset important for STEM graduate students throughout and beyond their degree program. The formative communication training experience during a PhD program often focuses on written and oral communication, typically characterized by informal instruction by the primary research advisor with occasional support from faculty collaborators or committee members. This common approach to training and education of such a critical skillset lacks the breadth of preparation required to meet the variety of professional communications that will be required of PhD holders when they enter the STEM workforce.

In that vein, the National Academies identified communication skills as one of a handful of competencies that should characterize all STEM PhD education [1]. This recommendation also points to the need for educating STEM PhD students for the breadth of professional communication they will encounter, which includes all STEM professionals, other sectors that interact with a STEM professional's body of work, and the public at large.

Moreover, the need for and shortcomings in training around effective communication skills among graduates is evident even outside the purview of higher education professionals. Employers of STEM PhDs list communication skills as one of the core transferrable skills they value and are seeking in STEM advanced degree hires, and they go on to articulate the need for effective communication with a variety of audiences – both technical and laymen – in both written and oral formats [2]. During in-depth interviews, leaders from a range of STEM employment sectors also noted communication skills as a too-common skills gap in new STEM PhDs, pointing to lack of skills, confidence, and agility to adjust their communications between peer-experts, specialists from different disciplines, and general audience. This is consistent with the last five years of employer responses to the National Association of Colleges and Employers Job Outlook survey rating written and oral communication skills both in the top ten attributes they are seeking on a candidate's resume, and in most years one or both appear in the top five [3][1].

With both graduate training experts and employers agreeing on the need for effective communication skills among STEM PhD graduates, it is essential that institutions of higher education develop training and education around written and oral communication skills.

Efforts in STEM communication training. While the purpose of this literature review is not to create a comprehensive catalog of other graduate-level STEM communication training opportunities, there exist a handful of notable trainings offered by both universities and external entities. These trainings take the form of workshops, programs, and university courses with varying topical foci and depth of training. A 2015 COMPASS report details the landscape of science communication training in STEM graduate education, including an inventory of workshops, programs, and courses nationwide [4]. A further description of graduate science communication training programs will be included in the final paper.

STEM Graduate Careers

[1] Multiple years can be found on https://www.naceweb.org

In 2015, career outcome data for new STEM PhD graduates reported that less than half of employed STEM PhD holders were working at an educational institution, and that other sectors such as private for-profit or nonprofit or state and federal government made up the majority of STEM PhD post-graduate school employment [5]. This remained representative of post-graduate school employment when the SciComm program was administered in 2017 [6]. Despite these employment data and a 10-year decline in the overall rate of academic employment by new STEM PhD recipients, PhD curriculum and requirements largely continue to prepare STEM PhD students for faculty careers. Thus, it is important for PhD students to understand the breadth of post-graduate school employment given the range of employment sectors STEM PhD holders occupy.

The diverse career interests and employment of STEM PhD holders is not a new phenomenon, but the training and education of PhD students has not fully adjusted to meet the skills and preparation needed to succeed in these areas. The recent report by the National Academies outlines recommendations on how STEM graduate education could respond to employment trends, moving from the mindset that values preparing PhD students for academic research careers to one that recognizes and responds to the varied career paths PhD students are actually undertaking in sectors such as government, industry, or nonprofit [1]. Among these recommendations, the report recognizes the desire of STEM PhD students to be provided with opportunities for both career exploration to allow them to make informed career choices, and for career preparation in the knowledge and competencies needed to pursue their career interests.

SciComm Program

Given the importance of communication training for STEM PhD students *and* in better understanding post-graduate STEM career opportunities, the SciComm program was developed to train STEM PhD students. The breadth of possible communication mediums necessitated the program to identify a narrower subset of these skills to focus on. Therefore, SciComm was created with oral communication in mind and trained participants on both verbal and visual delivery. The program content also touched on presentations across STEM employment sectors, providing a career exploration opportunity as well.

The SciComm program was a 2-semester, intensive program funded by NSF (#1645058) designed to provide STEM PhD students scientific communication training paired with real-life, immersive opportunities to put that training into practice. The goals of the program were twofold:

1. To equip PhD students with training and experience to effectively communicate their research with a variety of audiences.
2. To expose students to a diverse set of future career opportunities available to STEM PhD holders.

With an immersive training experience in mind, the SciComm program integrated a variety of knowledge-based learning activities about communication, practice with communicating, and practical experience communicating with various audiences. Program participants also engaged with peers, practitioners, and professionals throughout the program.

The program curriculum included three primary components: a) bi-weekly seminar meetings, b) communication challenges, and c) mentorship by University alumnus/a. The three components were designed to integrate hands-on learning and practical application to help students meet the program goals.

Bi-Weekly Seminar Meetings. Students met for 2 hours every other week throughout the fall and spring semesters for a total of 15 seminar meetings throughout the program. The seminar meetings provided regular opportunities to learn, practice, and receive feedback on foundational communication skills (fall semester) and specific audience types that scientists regularly communicate with (spring semester). Examples of seminar topics include: audience analysis, message design, vocal and physical delivery, data visualization, using translational tools such as story and metaphor. During the second semester, students learned about specific audience types from professionals about the following communication audiences:

- public
- print and broadcast media
- policy makers
- business investors
- specialists from different disciplines
- non-profit organizations

Communication Challenges. Students were encouraged to participate in two presentations that required them to integrate the major skills and concepts from the seminar meetings to create and deliver a presentation to a real audience. These Communication Challenges took place primarily in the spring semester, were self-organized by the students, and travel awards were available through the SciComm program to support student travel and registration to participate in Communication Challenges of their choice. Students collectively participated in over 75 Communication Challenges during the program. Examples of Communication Challenges in which students participated include: Science Pub Night at a local distillery, academic conference presentations, a seminar for the local garden club, K-12 classroom presentations and after-school programs, and at a public night program at the University Observatory.

Mentorship. Each student was paired with a mentor who is a professional who engages with one of the audience types discussed in the program. Mentors were recruited by the program director and almost all mentors were University alumni; however, they were not necessarily from the same degree or major as their student mentee. Student/mentor pairs were formed by the program director based on major of student and mentor, as well as professional interests indicated by the student at the start of the program. Students met with mentors four times throughout the spring semester either in-person or virtually.

Final portfolio. As part of the SciComm program, PhD students created a portfolio of their work. The portfolio included video recordings of presentations throughout the program that students shared with the SciComm group through the Vimeo online platform. They also completed a professionally-recorded final video as a culminating work at the end of the program. This provided students with a tangible take-home product of their participation in the program and allowed students to document their progress throughout. Of note, the SciComm program was not a course and was coordinated by the program director and first author on the study. Students did not receive credit or grades; however, they did receive meaningful feedback on their work from the program director throughout the program.

The SciComm program was developed for STEM PhD students with oral communication skill development and career exploration in mind, though its impacts appear to be broader-reaching than these two goals. Our study also shows the impact of program participation include: self-confidence, belief in the importance of scientific communication, self-awareness of the need for continual improvement of communication skills, and the inter-related improvement of other skills such as research and teaching with communication skills.

Purpose

In order to better understand the impact of the SciComm program on STEM PhD students at our institution, we focused on four main questions:

1. To what extent are STEM graduate students confident in communicating scientific ideas following the SciComm program?
2. What strengths and weaknesses exist in communication skills for STEM graduate students enrolled in the SciComm program?
3. How, if at all, did STEM graduate students gain a broader understanding of post-graduation STEM career options following the SciComm program?
4. What were STEM graduate students' perceptions of the SciComm program?

Methods

We used a mixed methods approach [7] to explore the impact of the SciComm program on STEM graduate students. Below we describe the research study participants, data collection and analysis.

Participants

A total of 28 STEM graduate students from 11 departments participated in the SciComm program at the University of Virginia during the 2017-2018 academic year. Of the 28 students who started the program, 28 completed the first semester, 24 started the second semester, and 22 completed the entire program. Attrition was primarily attributed to a time conflict between program seminar meetings with a degree requirement (class, lab meeting, etc.). Of the 28 program participants, 16 voluntarily participated in the research study (57%) and represented the majority of the program participant departments (Table 1). The majority of program participants were female (n=15, 54%) and U.S. Citizens (n=19, 68%), and similarly the subset of research participants was female (n=10, n=63%) and U.S. Citizens (n=12, 75%). While the research participation rate of SciComm program participants was low, the similarities in demographics between research and non-research participants suggest the data collected may be representative.

Table 1. *Departmental Breakdown of Graduate Students*

School	Department	SciComm Program, n (%)	Research participants, n (%)
Arts & Science	Astronomy	3 (10.7)	0 (0)
	Biology	2 (7.1)	0 (0)
	Chemistry	1 (3.6)	0 (0)
	Environmental Sciences	2 (7.1)	1 (6.3)
	Physics	5 (17.9)	4 (25.0)
Engineering & Applied Sciences	Biomedical	2 (7.1)	2 (12.5)
	Chemical	2 (7.1)	2 (12.5)
	Civil & Environmental	2 (7.1)	1 (6.3)
	Systems & Information	2 (7.1)	2 (12.5)
Medicine	Experimental Pathology	2 (7.1)	2 (12.5)
	Pharmacology	1 (3.6)	0 (0)
Total		28	16

Of the STEM graduate students who were research participants, the majority had completed candidacy, were NSF Graduate Research Fellowship Program (GRFP) awardees or honorable mention recipients, and intended to pursue an industry-related career (Table 2).

Table 2. *Graduate School Information and Future Career Intentions for Graduate Students who Completed the Post-Program Survey*

Category	Status	n (%)
Graduation school information	Graduated	1 (7.1)
	Defending in <6 months	1 (7.1)
	Completed candidacy	10 (71.4)
	About to complete candidacy	1 (7.1)
	NSF GRFP awardee or honorable mention	8 (57.1)
Career intentions[a]	Education	5 (35.7)
	Government	6 (42.9)
	Non-profit	6 (42.9)
	Industry	7 (50.0)

Note. n=14. [a] total n and % are greater than 14 as graduate students could choose more than one option.

Data collection

Multiple data sources were collected as part of this IRB approved study, including a post-program survey, focus group, and program artifacts.

Post-program survey. The post-program survey was electronically sent to program participants in summer 2018 following completion of the program. The survey included both Likert and open-ended questions to explore participants' communication confidence, understanding of STEM careers, and perceptions of the SciComm program (Supplemental A). To assess participants' confidence, we used the Self-Perceived Communication Competence Scale (SPCC) [8]. To assess communication skills, the two authors developed a series of three scenarios that asked for participants' description for strategizing and communicating their research to different audiences. Participants also indicated familiarity with STEM careers after the program and retrospectively before the program to explore changes in understanding. Finally, a series of open-ended questions were developed by the two authors to obtain feedback on the SciComm program.

Focus group. After completing the post-program survey, participants were invited to participate in a 60-minute focus group. To further probe participants' experiences and outcomes from the SciComm program, the two authors developed a focus group protocol (Supplemental B). A total of eight participants participated in the focused group in August 2018, run by the second author.

Program artifacts. Course artifacts collected over the 2017-2018 academic year, which include: presentation videos, seminar participation attendance, reflections (three per student), post-course feedback forms, and mentor profiles. Of the four communication videos completed by students, the authors chose to include videos on communicating to a policy maker and communication to a general audience (n=23 videos). These data help to triangulate survey and focus group data.

Data analysis

Descriptive statistics and frequencies were calculated for quantitative survey data. Graduate students' self-reported awareness of different STEM careers before and after the program were analyzed using a non-parametric Wilcoxon Sign-ranked test (the equivalent of a paired t-test for non-normal data). Open-ended survey responses, program documents, and focus group transcript were analyzed through an iterative, inductive process lead by the second author. These data sources were combined to create topics around the three main goals of the program (improved communication skills, improved communication confidence, improved understanding of STEM careers). Themes around participants' perceptions of the SciComm program were also inductively identified from the qualitative data. For example, across multiple data sources participants continued to discuss how the SciComm program was beneficial to them beyond just their communication skills. Three different external benefits were identified from these data, and confirming data were identified to characterize each benefit. The final themes and supporting data were agreed upon by the two authors.

The two authors also developed a video rubric to characterize participants' communication skills from their presentation videos. Using best practices for rubric development e.g. [9] and effective communication strategies, the two authors identified the outcomes and dimensions that would characterize effective scientific communication broadly (e.g., eye contact, use of jargon) as well as for specific audiences (e.g., specificity of an ask to a policy maker). After initial development of the rubric, the authors individually watched and coded four videos with the Scientific Communication Skill Video Rubric. The authors met to discuss and significantly revised the rubric. For example, in the initial rubric, the authors included an outcome category of 'presentation skills', which was expanded in the second rubric into 'vocal presentation skills' and 'physical presentation skills'. Subcomponents of these two categories were also developed. The vocal presentation skills included vocal structure (e.g., pace, filler words) and strength (e.g., vocal fry, stumbling), while the physical presentation skills included movement (e.g., meaningful gestures) and eye contact (e.g., eye contact made but not intense).

The three dimensions were expanded into five dimensions that spanned from novice to expert. The authors then individually recoded the four videos, discussed their coding, and made smaller revisions to clarify the rubric dimension descriptions. The authors chose a new set of four videos and individually coded these videos with the revised rubric to make final changes to the rubric. The final rubric included 12 outcomes on five dimensions (Table 3 and Supplemental C), with the 'Organization/structure' outcome varying based on the type of audience focus of the video. For example, we coded policy video organization based on the 'use of evidence', 'credibility of self', and 'ask'.

Table 3. *Descriptions of 12 outcome measure communication skills categories*

Category	Sub cat	Expert description
Relating to audience	---	Use an element that identifies with the audience (e.g., example, facts, analogy, or story) and explicitly demonstrates why audience should care (e.g., application, emotion, 'Imagine if you…')
Language/jargon	Jargon	Does not use terms and phrases specific to their scientific discipline, or if they do, defines them in a way that the audience can understand. Uses a general term for the scientific jargon
	Sentence structure	Uses short sentences with smaller words
Research	---	Couch own research in the broader context of the field (e.g., what may be known, how is this novel) in a balanced way that aligns with needs of audience
Organization/ structure (Policy)	Use of evidence	Uses specific data from research or external sources; Provides source of data (e.g., from my own research, from NASA)
	Credibility of self	Establish credibility of self with specifics (e.g., years doing research, position, location of work);
	Ask	Make a specific ask (e.g., dollar amount, task of policy maker)
Organization/ structure (General)	---	Include all of the following: Issue, problem, so what, solutions, benefits
Vocal Presentation skills	oral structure	**None** of the following are present: filler words; inappropriate pace (too fast or too slow); monotone; long pauses
	vocal strength	Sentences that are vocally strong throughout (e.g., no stumbling through words trailing off at the end of the sentence, vocal fry)
Physical	movement	Use of movement & gestures is intentional (e.g., (e.g., no pacing, no rocking), appropriate (e.g., small movements for small room/audience, large movements for larger room/audience), add value to the message, and aligned with message (e.g., use numbers for each point made)
	eye contact	Eye contact is made with the audience without locking in on an individual person/point; [for videos] the eye contact is not noticeable

The authors then individually coded all videos (n=31[2]) and discussed any discrepancies. Because the scale was expanded to five dimensions, the authors chose to identify 'agreement' as scores for each outcome no more than one dimension apart (e.g., novice/beginner,

[2] The total number of videos used to calculate reliability included videos made by STEM graduate students who did and did not consent to participate in the study.

proficient/competent) and disagreement as scores for each outcome more than one dimension apart (e.g., novice/proficient, beginner/expert). The overall interrater reliability from individual coding was 76.5%, after which all discrepancies were discussed. After discussion, the two authors came to an agreement on all discrepancies.

Results

Overall participants had a positive experience in the SciComm program and have improved confidence in and ability to communicate their scientific research to different audiences. Further, participants gained a more in depth understanding of STEM careers. The program also appeared to have a broader impact beyond communication. While the study participation was limited to 57% of program participants, the data still provide a meaningful understanding of the effectiveness of the SciComm program. Below we present the qualitative and quantitative data to answer our four research questions.

Confidence in Communicating Scientific Ideas

Graduate students' perceptions about their ability to communicate suggested they were not necessarily aware of their confidence coming into the program but that the program exercises such as videotaping and practicing with a peer helped them become aware of their confidence (or lack thereof). For example

> *One thing that has stuck with me is the importance of appearing confident while speaking. As a woman, I think I struggle to do this more than others. So now I am consciously thinking about how I hold myself in pretty much all aspects of life…(Post-course feedback)*

The strategies taught during the SciComm program that seemed to help reduce nervousness and improve graduate students' confidence included the vocal exercises, practicing communication, and hearing from speakers:

> *Yeah. So the one thing that I've really noticed is that, in both talks with the general public or with experts in my field, I've become much less nervous when I talk. And I think that's a combination of practicing talks and also the techniques that we've learned help think about what's happening to our body when we're speaking and how to control that. It's been very helpful. (Survey)*

> *Vocal exercises → fun(ny) and really do calm my nerves. (Post-course feedback)*

> *The experiences of science communications from speakers who have been practicing skills for years also encourage me to communicate bravely and efficiently. (Post-course feedback)*

Graduate students also reported their level of confidence in communicating to audiences of various sizes and familiarity (Figure 1, Table S3). Overall, graduate students who completed the survey (n=15) appeared to be most confident in one-on-one peer communication about their scientific research. Confidence in communicating with strangers was highest for large groups. On average, graduate students were least confident in one-on-one communication about their scientific research with strangers.

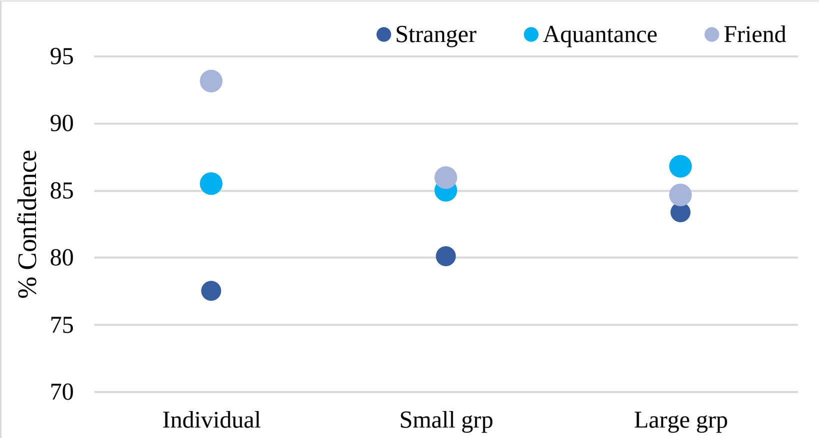

Figure 1. Participants' confidence in communicating to differing audience size and level of familiarity

When asked about what they would like to learn more about, graduate students shared their lack of confidence in communicating one-on-one with strangers:

> *I would say that, the one thing I think is one of my weaknesses still is that I'm more comfortable with presenting in front of big groups now, but I think one-on-one communication for networking is still an awkward phenomenon for me, so that's what I would like to improve. (Focus group)*

Thus, the SciComm program components most important for helping graduate students identify and improve their confidence in communication included: videotaping themselves, opportunities to practice, vocal exercises, and hearing from speakers on their experience with communication. While graduate students appeared to be fairly confident in their ability to communicate, they were least confident about doing so in one-on-one meetings with people they did not know. They would have appreciated learning more about how to do this as it related to networking.

Communication abilities

Participants' strengths and weaknesses in their communication abilities came from coded videos, survey, and focus group data. Based on the video recordings, participants were most skilled in relating to their audience and in their vocal strength and least skilled in their physical movements and eye contact (Table 4).

Table 4. *Overview of communication skills observed in video recordings*

	Audience	Jargon	Sentence structure	Connection to research	Oral structure	Vocal strength	Physical movement	Eye contact
Mean	4.22	3.58	3.89	3.50	3.13	4.43	2.67	2.65
SD	1.05	0.56	0.64	1.31	0.81	0.66	0.85	1.12

Note. Total videos = 23.

From the self-reported survey and focus group data, graduate students reported learning most about audience analysis, reducing jargon, and presentation skills. These experiences appeared to lead to improved use of communication outside of the SciComm program. When asked about what they learned from the SciComm program, graduate students frequently discussed the importance of tailoring research talks to different audiences based on the audiences' background:

> *Most importantly, I learned a lot about working to meet people at their CURRENT level of expertise at the beginning of my presentation and then working up to my specific scientific topic. (Survey)*

In addition to tailoring their communication, graduate students also reported they learned the importance of reducing the amount of jargon used in communication:

> *I learned about tailoring a message to a specific audience and how to explain complex technical subjects without using jargon. (Survey)*

Finally, the specific presentation skills that make for effective communication were also frequently reported by graduate students as an important communication skill they learned:

> *I learned how to make clear and concise figures, graphics, and slideshows. I also learned a little more about projecting my voice and keeping good posture during a presentation. (Survey)*
>
> *[I learned] design and utilization of tangible 3D visual aids (atom models etc. ...) for presentations, beyond 2D slides. (Survey)*

Graduate students also reported on Communication Challenge presentations they engaged in over the course of the SciComm program. These presentations were mostly in academic settings; however, additional presentations across audiences were also reported (Table 5).

Table 5. *Graduate students' number of Communication Challenge presentations to various audiences*

	Academic	Public	K-16	Non-profit	Media	Policy	Business
Total	44	10	13	3	2	1	1
Mean	3.38	.77	.38	.23	.15	.07	.07

Note. Total graduate students=15.

One graduate student articulated a communication experience they had that demonstrated their ability to effectively communicate to their intended audience:

> *In my internship, I recently gave a presentation where I had to explain an extremely technical concept to a room full of engineers who were mostly beginners in the subject. Other non-scientist members of the company were also there. I started from the point of view of a beginner and gave concrete, understandable demonstrations of the topic before transitioning into more abstract material. After the presentation, I received positive feedback from the group. About a week later, my supervisor mentioned that the CEO of our department had been in attendance, and had mentioned how much he liked the presentation. He wanted to know more about me and also asked when I would graduate. He also expressed disappointment that I was not a full-time employee. (Survey)*

Thus, graduate students learned audience analysis, ways to reduce jargon, and presentation techniques in the SciComm program that improved their communication skills. Graduate students engaged in mainly academic presentations outside of the SciComm program, and while it was not directly asked in the study, one student voluntarily reported that a presentation experience outside of the program was a success as a result of engaging in the SciComm program.

Understanding of STEM career opportunities

Graduate students' self-reported understanding of various career opportunities before and after the SciComm program. Their awareness of careers in policy, education, non-profit, and media were all significantly higher post-program (Figure 2). No significant differences were observed in their reported awareness of industry or public outreach related careers.

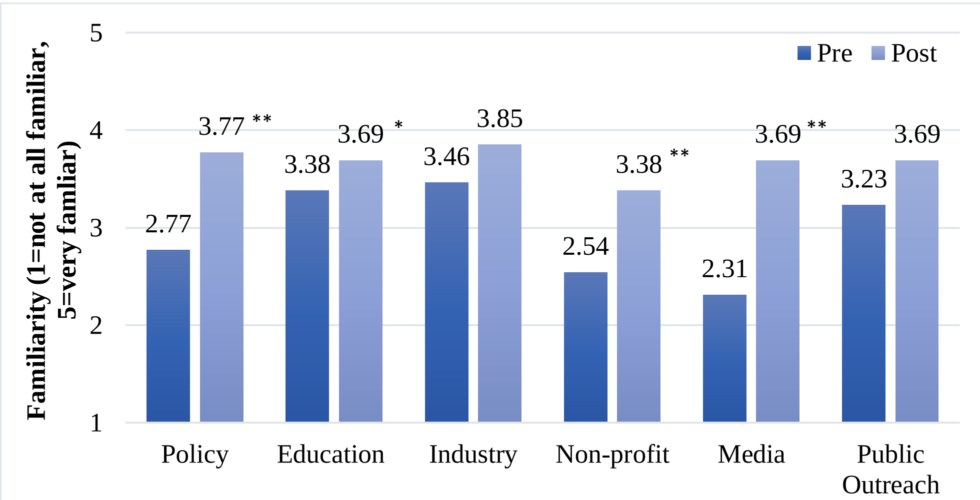

Figure 2. Changes in graduate students' self-reported awareness of STEM careers. * significant, $p<0.05$. ** significant, $p<0.01$.

Graduate students' depth of understanding about STEM careers was also impacted by their experiences in the SciComm program:

> *I have also learned more about tailor-making your career to suit multiple interests. This is important because I am trying to figure out how I want to continue to mesh STEM and policy interests in my career going forward. (Survey)*

> *Even though high-level industry jobs are rare, I feel that getting a Ph.D. still makes you highly employable, because there are lots of companies that would like to hire an employee with a STEM Ph.D., even if that company is outside of your field of study. In addition to gaining a lot of specialized knowledge, you learn many problem-solving skills during a Ph.D., and these skills tend to be generalizable to many industries. (Survey)*

Some graduate students also became more aware of the diversity of paths to get to various careers:

> *I'd say it's also reassuring just seeing the roundabout ways they [speakers/mentors] all ended up in their current career tracks. So, there's a future out there for all of us, even if it's not, we can't see it yet. We'll end up somewhere. So that was reassuring. (Focus group)*

These understandings of STEM careers seemed to stem from their engagement with the mentors, hearing various speaker talks, and completing a mentor profile assignment.

While the SciComm program expanded graduate students' understanding of various STEM careers, only three graduate students (21.4%) indicated their career intentions shifted as a result of the SciComm program. Most graduate students still maintained their intended career intentions (n=8, 57.1%). Two graduate students' (14.3%) career plans changed over the 2017-2018 academic year, but indicated the SciComm program did not impact this change.

SciComm Program Perceptions

Based on inductive coding of the qualitative data, it appeared that participants had both positive perceptions of the program and suggestions for improvement. Further, participants cited additional benefits from the program beyond the stated goals.

Helpful program components. The most commonly cited components of the program that were helpful for graduate students included: 1) mentors and mentoring relationships, 2) cross-disciplinary engagement, and 3) communication videos on Vimeo.

First, the mentor-mentee interactions were cited as important for graduate students' understanding various careers and networking capabilities:

> *It was just interesting just being able to ask her about her [mentor] career path, why she went with the path that she did, what exactly it's like working in her career, because it's something that I was kind of interested in doing myself. So it was good being able to get that kind of insider point of view on how being a writer is. (Focus group)*
>
> *Yeah, this class, this mentorship program helped get this connection for me that'll be useful going forward. (Focus group)*

Second, the graduate students appreciated the disciplinary diversity of their peers as they perceived it important for helping communicate to non-expert audiences:

> *The fact that we're all from different areas kind of helped get us all on even footing, because we're all expert in our field, but then we all have to bring it back to the fundamentals and explain it in a difficult way when you're used to thinking in such a high level. So I think that helped us be more cohesive and caring about each other. (Focus group)*
>
> *I enjoyed the academic diversity, which lead to great feedback. (Post-course feedback)*

Third, nearly all graduate students had little experience with creating communication videos, and the experience yielded mixed reviews. Some graduate students found the high-quality video extremely helpful:

> *I think coming out of the program with that tangible, high production value video that we did at the end is gonna be useful thing. It's, you know, this program wasn't just a line on our CV or anything. It's like we have something we can actually show that we've done that, I think they all turned out pretty well, so, it was, you know, a good, actual piece of art communication that we can show off. (Focus group)*

Some changed their mind:

> *Yeah, before joining this program, I was very reluctant to rehearse. I hate recording myself and seeing myself. But this one kind of forced me to do that. Actually it's kind of a necessary tool, so I'm less uncomfortable recording myself now. (Focus group)*

And some did not like the video recordings even at the end of the program:

> *I didn't like the videos! I never felt comfortable with them and would have much preferred scheduling in-class or outside of class times to present to one another and get feedback that way* (Survey)

Thus, despite the videos having mixed reviews, they appeared to be an important component in supporting graduate students' development of and confidence in communication.

Benefits of the program for graduate students. Based on the qualitative data from course artifacts, surveys, and focus group, there were three additional benefits that many of the graduate students discussed: 1) the importance of scientific communication, 2) the need for continual improvement of communication skills, and 3) the improvement of other skills such as research and teaching.

First, multiple graduate students discussed a fundamental shift if their beliefs about the importance of scientific communication that stemmed from their experience in the SciComm program. For example, explaining a peer activity one graduate student stated:

> *I personally believe if you teach a two year old kid, you have to kneel down and make eye contact, right? So it's like figuratively, physically. But intellectually also, we should do that. We kind of don't do it, and sometimes we think it's bad to do that because it's like we dumb ourselves down. We have to use these big words, right? In grad school. So I could give up that sort of paradigm. I was able to reevaluate myself as a person that can break things apart and spoon-feed or puree, or do something in a way that even somebody who's not very interested, who's not familiar, can understand. It's like some internal change, not even communication. It's changed the way I think about communication. (Focus group)*

As part of what they learned from the SciComm program, other graduate students commented:

> *I learned that scientists are particularly crucial in providing constructive policy advice. Even as civilians calling into their representatives' office, scientists can provide valuable expertise that can help to inform politicians and their staff members. (Survey)*
>
> *My experiences in this class have cemented by belief that the act of communicating scientific information is every bit as complicated and important (and, I would argue, more important) than the act of creating information through research. (Post-course feedback)*

Second, graduate students articulated their need for continually improving their communication skills beyond the SciComm program. They were able to identify the places in which they still needed to improve:

> *I still feel challenged by presenting efficiently, even though I have improved myself a lot through this program. And I still need to work on that. (Post-course feedback)*
>
> *I still probably need to practice my "elevator pitch" and explaining my research on-the-fly. (Post-course feedback)*
>
> *I think I still need to improve how much I practice for presentations. I struggled with that the whole class and I'm still working on it. But now, instead of not practicing at all, I practice at least once or twice. But not two weeks before, like Amy said we should. (Focus group)*

Third, graduate students' survey and focus group responses elicited different ways in which the SciComm program improved their skills in research, mentoring, and teaching.

I think by practicing communication, other stuff has also changed. For example, how our research might be used. So previously what I know is just how this experiment works, something like that. But, before I entered a program, once I have explained it to somebody, my research is about a bunch of atoms they may decay very fast under certain circumstances. And that person just asks, "Okay, so got this for what? If they decay really fast, are you planning on doing a brighter light bulb or something with that?" And I really haven't thought of what this experiment can do, but after practicing in this program, we need to understand what our audience need from our presentation. It really drives me to think what my experiment can actually provide to the greater community. (Focus group)

I'd say that learning, so, from the program, learning how to become a better mentor and teacher as well. (Focus group)

I learned how to help myself and others better create narratives for their science communication. (Survey)

Thus, the SciComm program enabled the graduate students to value communication, consider ways to continue to improve their communication skills, and translate their skills learned in SciComm to their research.

Suggestions for Improvement. There were very few suggestions for improvement from graduate students. There was mixed feedback on the structure of the overall program; some graduate students liked the current structure (i.e., semester of coursework, semester of guest speakers) while others would have appreciated these activities being spread over the academic year:

I think my suggestion would be to alternate between communication skill lessons and guest lecturers throughout the entire academic year. We need to learn concrete skills, but it really helps to see the application of those skills from professionals out in the field. I think that interspersing the communication lessons with guest lecturers would help to "ground" the lessons in reality. Essentially, the guest lecturers would give us a really clear picture of how the lessons that we just learned can be applied to real-life situations. (Survey)

The types of speakers represented was also something that graduate students would like to see modified slightly:

For me, I want to be that kind of person [academic with outreach] rather than completely deviating from academia. So, I want to know what those kind of persons are doing, and I think there are all sorts of other people that branch out and I want to know more about their stories as well. (Focus group)

Finally, graduate students also had suggestions for expanding the program beyond STEM graduate students:

People don't care about it. So the biggest thing, improvement, if it's possible, is to do is like ... to get people who are not excited about communication to the program. (Focus group)

Start a similar workshop to real professors who teach, so teaching quality in the university can be improved. (Survey)

Discussion

Surveys, focus groups, and program artifacts from graduate students demonstrated that the SciComm program substantially met its goals of training PhD students to effectively communicate their research with a variety of audiences and exposing them to a diverse set of STEM PhD career opportunities. While these goals are considered essential components of STEM PhD education, if and how they are addressed during PhD training can vary widely. Overall, participants in the SciComm program had a positive learning experience and offered few suggestions for improvement. While the research participation was limited (57%), our work with these participants as program director and researcher suggest program participant experiences were similar.

Oral communication

The SciComm program focused communication skills training primarily on oral presentation skills. While participants' skill levels vary across the different foundational communication skills included in program trainings, students completed the program feeling more confident and practiced in the program skills. Specifically, graduate students reported learning how to perform an audience analysis, reduce their use of jargon, and improve their presentation skills (posture, voice, and visuals) as a result of the SciComm program. While students pointed to presentation skills as an area of growth, researchers noted from the video recordings that students were least skilled in the physical movement and eye contact of their presentation skills. Both of these skill areas were addressed in the training students received during program meetings; however, guidelines on camera angle, distance, and framing were not specified in video assignment instructions. This may have led to poor demonstration of these skills in the videos used for this study. Furthermore, a quantitative analysis of individual skill improvements over the duration of the program were not addressed in this study.

Career paths

The program was also successful in improving students' understanding of various STEM careers, with significant gains in awareness of careers in policy, education, non-profit, and media. Many students reported the desire to continue to pursue an academic career. Despite little change in participants' career interests, this intentional pairing of communication skills training with career exploration was a particularly valued component, allowing students the opportunity to make an informed decision about potential careers. The SciComm program provided a more in-depth understanding of STEM PhD career pathways both through professional presenters during the second semester of program meetings and through the alumni mentorship component. As many students reported the desire to continue to pursue an academic career, providing additional opportunities for understanding academic careers that explicitly utilize communication skills may be an important addition.

Additional benefits

Beyond the stated program goals, this study revealed that students believed they had gained additional, unexpected benefits from participating in the program. During the study, participants discussed the additional program benefits: 1) a belief in the importance of scientific communication, 2) the need for continual improvement of communication skills, and 3) the improvement of other skills such as research and teaching. These revelations bring up the potential for future studies into the motivation of students who choose to participate in professional skills training, in this case scientific communication training, and how training in a competency that is considered a transferrable professional skill directly or indirectly impacts the traditional measures of graduate student success.

Recommendations for other programs

We have compiled a list of suggestions from the data and our experiences that may help others create effective STEM PhD communication programs. These include:

- Providing opportunities for students to learn about one-on-one networking and communication strategies.
- Using career interest data from students to more explicitly shape programming around career exploration. For example, finding a balance of exploring career paths of greatest interest to participants, while still maintaining students' broad exposure to PhD STEM career pathways.
- Incorporating social media training into the content of a communication program.

Lessons Learned from Implementation

The first author and program director's reflection on implementation of the program provides additional insights that other directors may find helpful. While there may not be one single individual or a collection of individuals across a university with the knowledge and experience to lead trainings, an institution could still organize such trainings relying on alumni and other practicing professionals. Further, institutional support is essential to the longevity and success of a communication program. We recommend considering the following aspects when seeking institutional support:

- *Funding*. A scientific communication program could be administered on a very modest budget. For SciComm, the professional videography and student support for registration and travel to Communication Challenges was the largest program expenses aside from the Program Director salary. While meaningful to the overall program outcomes, a program could easily be formed to capture similar ideas at decreased or no expense.
- *Value.* Reiterating the recommendations from the National Academies of Sciences, broad institutional support is also necessary for the longevity and success of a communication training program in that it must be apparent to all institutional levels that communication skills are an important and valued component of graduate education. Without value for these skills, time and resources will not be allotted.
- *Time*. Graduate programs are already packed with coursework, teaching, and research. Faculty may not support students in these types of programs. Thus, the institution needs to find mechanisms for creating time and space in graduate education for students to participate in communication-based professional development. This may include addressing faculty support of student participation, and creating transferrable incentives in the form of course credit, certificates, or a portfolio of work that participants can use demonstrate their training to employers.
- *Accessibility.* To have the largest impact, communication programs should be available and have the capacity to include any student who is interested. Offering professional skills programs such as this one independent of an academic program or unit can help provide access for students in departments or schools that are not equipped for integrating

formal training in these skills. In order to ensure capacity, broad institutional support is essential in carving out personnel, resources, and student access across the university.

Conclusion

In conclusion, the SciComm program's success in meeting and exceeding its goals for STEM PhD student communication training and career exploration suggests that this is one program model to address the concerns and recommendations raised about career-ready communication skills among STEM PhD graduates. The program communication skill content is limited in that the primary focus is oral presentation skills, though many of the concepts are more broadly applicable to other types and formats of STEM communication. Overall, graduate students were very complimentary about the SciComm program, which they reported as having a far-reaching impact beyond their immediate communication skills. They appreciated the impact of the program and would like to see it continue and expand to graduate students who do not care about communication as well as to professors to help improve teaching.

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Supplemental A

SciComm Survey

Communication Competency[3]:
Directions: Below are twelve situations in which you might need to communicate about your scientific research. People's abilities to communicate effectively vary a lot, and sometimes the same person is more competent to communicate about their scientific research in one situation than in another. Please indicate how **competent you believe you are to communicate your scientific research** in each of the situations described below. Indicate in the space provided at the left of each item your estimate of your competence.
Presume 0 = completely incompetent and 100 = competent.
_____1. Present a talk to a group of strangers.
_____2. Talk with an acquaintance.
_____3. Talk in a large meeting of friends.
_____4. Talk in a small group of strangers.
_____5. Talk with a friend.
_____6. Talk in a large meeting of acquaintances.
_____7. Talk with a stranger.
_____8. Present a talk to a group of friends.
_____9. Talk in a small group of acquaintances.
_____10. Talk in a large meeting of strangers.
_____11. Talk in a small group of friends.
_____12. Present a talk to a group of acquaintances.

You work for a pharmaceutical company as a senior scientist and have been asked to make a presentation to the board about a promising new finding for a compound you are researching that could be a more effective treatment for a disease. Describe the **steps you would take** in deciding what to present and how to communicate it to this audience.

You are an assistant professor at a university and have been contacted by a reporter from the New York Times who would like to interview you about a recent journal article that you published on your research. Based upon this scenario, write a **clear communication goal** for your conversation with the reporter.

You work for NASA's Mars Exploration program and are in charge of sharing the newest findings in a world-wide live televised event. A review of social media outlets shows that the public believes NASA has found life on Mars, when in reality NASA has found ancient organic materials and methane. Based on this scenario, **what would you present** about the new results and **how would you communicate** it to the international audience.

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Understanding of STEM careers:

1. Do you currently have a career plan?
2. If Yes: What are your career plans after graduation?
3. What sector do you intended to look for careers in when you finish your degree:
    a. Education
    b. Public or private industry
    c. Government
    d. Non-profit
    e. Further Education
4. Have your career plans changed following the SciComm program? If so, why? If not, why not?
5. Describe your understanding of the different STEM careers available for Ph.Ds.
6. How, if at all, have your understandings of the different careers changed over the course of the SciComm program?
7. Indicate your familiarity with the following careers **before starting the SciComm program**: (1=not at all familiar, 2=not very familiar, 3=somewhat familiar, 4=familiar, 5=very familiar)
    a. Policy
    b. Education
    c. Industry
    d. Non-profit or foundation
    e. Media
    f. Public outreach or public education

8. Indicate your familiarity with the following careers **after completing the SciComm program:**

SciComm program:

1. What did you learn as a part of the SciComm program?
2. What components of the SciComm program aided in your learning?
3. What were the strengths of the SciComm program?
4. What could be improved about the SciComm program?
5. The objectives of the program were for you to be able to:
    - identify and adapt your research communication for various audience types
    - understand the various STEM career opportunities available for Ph.D. holders

    To what extent do you perceive you met the program objectives?

Presentations:

1. Outside of the videos you recorded for the program, please tell us how many presentations you gave on your research in each of the following areas since September 1, 2017:
    a. Academic/expert (poster or oral)
    b. Public
    c. Policy-maker
    d. K-12 Education
    e. Higher Education

f. Media
g. Non-profit or foundation
h. Business
i. Other: Please describe

Demographics:

1. Name
2. Department
3. Are you an NSF GRFP awardee or honorable mention?
4. Where are you in your Master's or PhD program (e.g., completed candidacy, about to defend your thesis or dissertation within the next 6 months, just graduated)
5. Proposed thesis or dissertation topic/title:
6. Gender
7. Race
8. What experience did you have communicating about scientific research/ideas prior to the SciComm program?

Supplemental B

SciComm Focus Group Interview Protocol

1. Please share your first name and department.
2. Thinking back, why did you decide to participate in the SciComm program?
3. What was your experience like in the SciComm program?
4. Can you describe how you interacted with your peers during the program? With your mentor?
5. In what ways, if at all, have you made improvements in your ability to communicate your scientific research to various audiences?
6. What do you wish you could do better in communicating your research to various audiences?
7. What, if at all, do you think you have learned about various STEM careers as a result of participating in the SciComm program? What component(s) of the program informed this?
8. What, if at all, do you think you have learned about yourself from participating in the SciComm program? What components(s) of the program informed this?
9. What components of the SciComm program were most important in supporting you in as a STEM graduate student?
10. What changes could be made to the SciComm program to improve it in the future?
11. Is there anything else we should know about your experience in the SciComm program?

Supplemental C

Scientific Communication Skill Video Rubric

Category	Sub cat	Novice (1)	Beginner (2)	Competent (3)	Proficient (4)	Expert (5)
Relating to audience	---	No example		Use an example that audience identifies with but may not care about (e.g., using American football example with non-American audience)		Use an element that identifies with the audience (e.g., example, facts, analogy, or story) and explicitly demonstrates why audience should care (e.g., application, emotion, 'Imagine if you…')
Language/jargon	Jargon	Uses jargon without defining the terms and does not try and generalize the jargon to a more broad audience		Don't use discipline specific jargon but sometimes uses jargon that is a bit more general to STEM but not suitable for a general audience		Does not use terms and phrases specific to their scientific discipline, or if they do, defines them in a way that the audience can understand. Uses a general term for the scientific jargon
	Sentence structure	Sentences are so complex, wordy, or full of non-jargon advanced words that the audience cannot understand		Sentences are longer and may have some more complex/advanced vocabulary		Uses short sentences with smaller words
Research	---	Missing either discussing of own research or broader context		Couch own research in the broader context of the field (e.g., what may be known, how is this novel) that is unbalanced or not targeted to audience		Couch own research in the broader context of the field (e.g., what may be known, how is this novel) in a balanced way that aligns with needs of audience
Organization/ structure (Policy)	Use of evidence	Not sharing specific data from research or external sources		Uses specific data from research or external sources without providing sources		Uses specific data from research or external sources; Provides source of data (e.g., from my own research, from NASA)
	Credibility of self	Not sharing details about self		Not enough information provided about self to determine credibility		Establish credibility of self with specifics (e.g., years doing research, position, location of work);
	Ask	No ask is present		Not enough detail in ask		Make a specific ask (e.g., dollar amount, task of policy maker)

Category	Sub cat	Novice (1)	Beginner (2)	Competent (3)	Proficient (4)	Expert (5)
Organization/ structure (General)	---	Missing 3 or more message box components		Missing 1-2 of the message box components		Include all of the following: Issue, problem, so what, solutions, benefits
Vocal Presentation skills	oral structure	The following are present and detract from the message: filler words; too fast/slow pace; monotone		**Some** of the following may be present: filler words; too fast/slow pace; monotone		**None** of the following are present: filler words; inappropriate pace (too fast or too slow); monotone; long pauses
	vocal strength	Sentences are vocally weak and detract from the message		Most sentences are vocally strong throughout		Sentences that are vocally strong throughout (e.g., no stumbling through words trailing off at the end of the sentence, vocal fry)
Physical	movement	Physical movements are such that they detract from the message (e.g., excessive rocking, large hand movements not aligned with presentation, no movement at all)		Some movements/ gestures are not intentional, don't add value or not well-aligned with the message or there are no gestures but still some movement		Use of movement & gestures is intentional (e.g., (e.g., no pacing, no rocking), appropriate (e.g., small movements for small room/audience, large movements for larger room/audience), add value to the message, and aligned with message (e.g., use numbers for each point made)
	eye contact	No eye contact with the audience or eye contact detracts from the message (e.g,. staring intensely at one person/spot/reading material for entire message)		Eye contact is made with the audience but may be too direct or indirect (e.g., some reading of material that is noticeable)		Eye contact is made with the audience without locking in on an individual person/point; [for videos] the eye contact is not noticeable