Research Article

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Science Communication Training Imparts Confidence and Influences Public Engagement Activity

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The impacts of science are felt across all socio-ecological levels, ranging from the individual to societal. In order to adapt or respond to scientific discoveries, novel technologies, or biomedical or environmental challenges, a fundamental understanding of science is necessary. However, antiscientific rhetoric, mistrust in science, and the dissemination of misinformation hinder the promotion of science as a necessary and beneficial component of our world. Scientists can promote scientific literacy by establishing dialogues with nonexperts, but they may find a lack of formal training as a barrier to public engagement. To address this, the American Society for Biochemistry and Molecular Biology (ASBMB) launched the Art of Science Communication course in 2015 in order to provide scientists at all career stages with introductory science communication training. In 2020, we conducted a retrospective survey of former participants to evaluate how the course had impacted participants' science communication behaviors and their confidence engaging with nonexperts, as well as other benefits to their professional development. We found that scientists were significantly more likely to communicate with nonexpert audiences following the course compared to before (77% versus 51%; $P < 0.0001$). In addition, quantitative and qualitative data suggested that scientists were more confident in their ability to communicate science after completing the course (median of 8, standard deviation [SD] of 0.98 versus median of 5, SD of 1.57; $P < 0.0001$). Qualitative responses from participants supported quantitative findings. This suggested that the Art of Science Communication course is highly effective at improving the confidence of scientists to engage with the public and other nonexpert audiences regardless of career status. These data-driven perspectives provide a rationale for the implementation of broadly accessible science communication training programs that promote public engagement with science.

KEYWORDS science communication, science literacy, public engagement, STEM education

INTRODUCTION

Scientific literacy is critical to the advancement of modern society, and its impacts are interwoven across socio-ecological levels. Information regarding scientific discoveries and novel technologies is being disseminated at an unprecedented rate and is now more publicly accessible than ever. While there are tremendous benefits to a more egalitarian scientific ecosystem, there are also great societal risks if scientific literacy is not prioritized as a personal, cultural, economic, or democratic imperative (1, 2). Antiscientific attitudes and the spread of scientific misinformation have become increasingly more common over the past several years, posing a grave risk to public health, political stability, and environmental sustainability (3–5). Scientific literacy can counteract or serve as an immunization against misinformation and antiscientific rhetoric (6–8). The link between public engagement and

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increased science literacy is most often observed through citizen science projects, in which the public directly engages with the scientific process (9, 10). Other informal science education events may lack evaluation and follow-up to study this trend directly. However, a few studies have suggested that communities gain science literacy with these program types through formal surveys distributed at events and sustained engagement as evidenced by local financial support, requests for programming, and event attendance (11).

While the scientific community overwhelmingly agrees that scientific literacy is important (1, 12), only within the past decade has there been a pronounced movement to increase engagement with the public or nonexpert audiences through science communication and outreach, particularly among undergraduate and graduate students, postdoctoral fellows, and early-career faculty (13, 14). This is not due to a lack of attention and effort on the part of educators; the need to develop science communication curricula has been articulated by stakeholders at every level of formal education. In 2018, the National Academies of Sciences, Engineering, and Medicine released their recommendations in "Graduate Education in the 21st Century," whereby graduate students should "[a]cquire the capacity to communicate, both orally and in written form, the significance and impact of a study or a body of work to all STEM professionals, other sectors that may utilize the results, and the public at large" (15). Despite these efforts, the mainstay of science communication training has focused almost exclusively on the skills required to communicate effectively within the scientific community, such as grant writing, manuscript preparation, or delivering presentations. Very few scientific training programs exist that focus on the skills needed to establish dialogues and build relationships with nonexperts. Even without formal science communication education, some scientists chose to develop these skills by engaging with others in public forums. Studies have shown that scientists have several motivations for this interaction, including positive attitudes toward the experience, believing they will make a difference, and time to incorporate such activities into their career. Self-efficacy and norms related to public engagement are also associated with willingness to engage (16–18). The self-efficacy point is particularly important in that it suggests that scientific training programs designed to improve skill levels and increase confidence levels may act as drivers to actual science engagement.

To address this issue, the American Society for Biochemistry and Molecular Biology's (ASBMB) Science Outreach and Communications Committee developed the Art of Science Communication (ASC) course, an 8-week online course designed to provide scientists with the fundamental skills and confidence to engage with nonexpert audiences (19). The course emphasizes bidirectional dialogues, rather than lecturing, and understanding different audiences. It introduces students to communication concepts such as narrative storytelling, the use of analogies, framing, and connecting with an audience by leveling the playing field.

Since its launch in 2015, the online course has been offered a total of 18 times, with over 630 participants enrolled and support by 85 course alumni who return as course facilitators. The course utilizes a flipped-classroom model; participants watch lecture videos, access homework, and view other supplemental content online. Course facilitators lead weekly small discussion groups, in which participants review course content and assignments. Presently, the course is offered 2 to 3 times per year, with approximately 8 to 10 discussion groups per session. In fact, course registrants consistently exceed the number of spots available within the small-group discussion sessions, leading to a waiting list. Additionally, the course has been adapted by several universities into a semester-long blended format, offered 19 times and enrolling over 300 students at the undergraduate and graduate levels. We have been overwhelmed by the response from the scientific community; however, consistent overenrollment of a course does not necessarily demonstrate that the course is meeting its goals and objectives. To this end, we conducted a retrospective survey to assess participants' engagement with science outreach and communication efforts and to evaluate any self-reported benefits of the course particularly related to communication and professional development.

METHODS

Survey instrument

A 36-item survey instrument was designed to assess the impact of the ASBMB Art of Science Communication course on participants' engagement with science outreach and communication efforts (see Text S1 in the supplemental material). The survey contained sections related to demographics, current employment or educational status, comfort and experience participating in science outreach and communication, motivations for participating in the course, and self-reported benefits from participating in the course. The survey also contained several open-ended questions related to participants' perceived science communication skill development and personal goals achieved by taking the course.

Participant recruitment

An invitation to participate in the survey was emailed to individuals who had participated in the ASC course between the years 2015 and 2020 on 12 October 2020. A follow-up email was sent to the individuals who had not yet completed the survey on 30 October 2020.

Data analyses

The institutional review boards of Northwestern University and University of Utah deemed this study exempt from further review.

Fisher's exact tests or chi-squared tests (GraphPad Prism, version 7.0) were used to compare categorical data. Kruskal-Wallis tests followed by Dunn's *post hoc* test were used to compare nonordinal data describing participants' confidence in their science communication skills. *P* values of <0.05 were considered significant.

Qualitative data analysis

Two authors (J.S.P. and C.M.S.) independently coded the open-ended survey items using an inductive approach with codes arising from the responses. Each coder developed a list of codes capturing recurring concepts in each open-ended item. Coders met to compare codes, resolve any disagreements, and reach consensus on the codes. Codes were then compiled in a codebook to describe and classify the data. Using the codebook, coders then independently coded the survey item responses again and met to compare coding results, resolve disagreements, and reach consensus. Coding was an iterative process, and with each discussion, the codebook was revised to account for added and/or deleted codes. Final codes were grouped into categories, and themes emerged from the categories.

RESULTS

Characteristics of survey respondents

A total of 451 ASC course alumni, for whom contact information was available, were invited via email to participate in the survey. Of those invited, 167 respondents completed the survey, achieving a response rate of 37%.

Demographic information regarding the respondents can be found in Table 1. Briefly, the majority of respondents were white (53%, *n* = 88), women (69%, *n* = 116), and currently working or studying within academia (78%, *n* = 130). The educational background of respondents varied: 45% of respondents (*n* = 75) indicated that they obtained a PhD, while 14% (*n* = 23) obtained a Master's degree, and 34% (*n* = 57) obtained a Bachelor's degree.

Since 2015, the ASC course has been offered in a fully online and blended (in-person) format. The majority of respondents (84%, *n* = 144) had taken the course in the online format, while a smaller proportion (16%, *n* = 26) had taken the blended course format. The number of respondents by course year and format can be found in Fig. 1. Eighty-seven percent of respondents (*n* = 146) indicated that they worked or studied within academia at the time that they participated in the ASC course (Fig. 1B). Of those individuals, 37% (*n* = 54) were graduate students, 29% (*n* = 42) held staff or other roles, 20% (*n* = 30) were postdoctoral fellows, and 14% (*n* = 20) were faculty (Fig. 1C).

TABLE 1
Respondent demographics

	N	%
Total respondents	167	100
Gender identity		
Male	48	29
Female	116	69
Gender non-binary or conforming	3	2
Prefer to self-describe or not say		
Race		
White	88	53
Asian or Pacific Islander	35	21
Hispanic or Latino/a/x	23	14
Black or African American	6	4
Multiracial	6	4
Prefer to self-describe or not say	9	5
Ethnicity		
Hispanic or Latino/a/x	31	19
Not Hispanic or Latino/a/x	139	83
Highest degree obtained		
BS or BA	57	34
MS or MA	23	14
PhD	75	45
Other or prefer not to say	12	7
Employment sector at time of course		
Academia	146	87
Government	7	4
Industry	5	3
Non-Profit/NGO	2	1
Other	7	4
Current employment sector		
Academia	130	78
Government	12	7
Industry	10	6
Non-Profit/NGO	2	1
Other	13	8

Motivations to participate in the ASC course

Prior to participating in the ASC course, only a small number of respondents had completed any prior science communication training (31%, *n* = 32). The majority of respondents indicated that they participated in the course to improve their overall ability to communicate (99%, *n* = 166) and to improve their presentation skills (96%, *n* = 161) or teaching skills (76%, *n* = 127) (Fig. 2A). To a lesser extent, respondents participated in the course for professional development reasons, such as to improve their CV or resume (57%, *n* = 96) or to obtain a promotion or advancement opportunity (30%, *n* = 50). Motivations to participate in the ASC course for professional development reasons differed by academic career stage. Faculty were

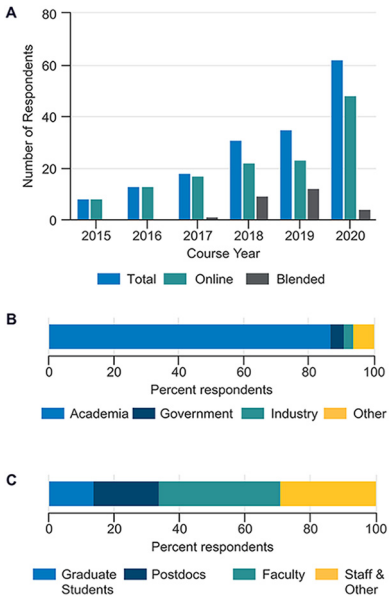

FIG 1. Characteristics of survey respondents. (A) Distribution of survey respondents by ASC course year and type. (B) Proportion of respondents who studied or worked within various sectors while participating in the ASC course. (C) Proportion of respondents who studied or worked within academia while participating in the ASC course.

significantly less likely to report participating in the course to improve their CV (20%, $n = 4$) compared to postdoctoral fellows (90%, $n = 18$), staff and others (67%, $n = 28$), and graduate students (65%, $n = 35$) [$\chi^2_{(3,\ n = 146)} = 22.3$, $P < 0.0001$]. In contrast, faculty were significantly more likely to report participating in the course in order to obtain a promotion or other professional opportunity (70%, $n = 14$), compared to graduate students (31%, $n = 17$), postdoctoral fellows (30%, $n = 9$), and staff and other individuals (10%, $n = 4$) [$\chi^2_{(3,\ n = 146)} = 23.6$, $P < 0.0001$].

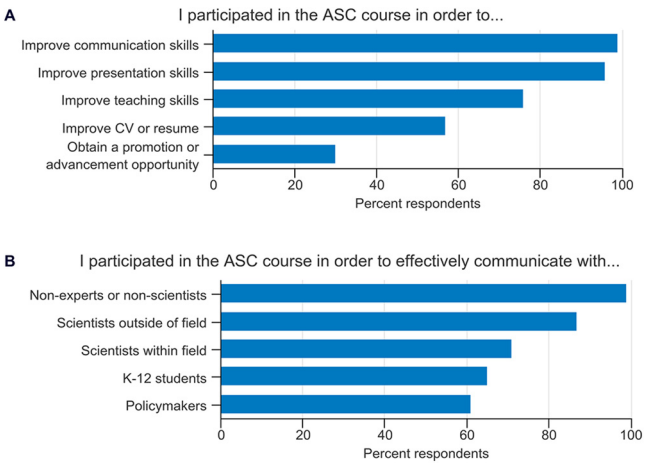

FIG 2. Participants' motivations for participating in the ASC course. (A) Proportion of respondents who agreed with each statement as it related to their motivations for taking the course. (B) Proportion of respondents who agreed with each statement as it related to the audience they hoped to be able to communicate more effectively with after taking the course.

Respondents indicated that they participated in the course in order to be able to effectively communicate with a variety of audiences (Fig. 2B). Nearly all of the respondents reported that they participated in the course to communicate with nonexperts or nonscientists (99%, $n = 166$), followed by scientists outside their field (87%, $n = 145$), scientists within their field (71%, $n = 118$), K–12 students (65%, $n = 108$), and policymaker-based audiences (61%, $n = 102$). Motivations to communicate with different audiences varied by academic role. Faculty members were significantly less likely to report participating in the course to communicate with scientists within their field (40%, $n = 8$) than were graduate students (70%, $n = 38$), postdoctoral fellows (73%, $n = 22$), or staff and other members (86%, $n = 36$) [$\chi^2_{(3,\ n = 146)} = 13.9$, $P = 0.003$]. In addition, faculty were significantly less likely to report participating in the course to communicate with K–12 student audiences (40%, $n = 8$) compared to graduate students (76%, $n = 41$), staff and others (71%, $n = 30$), and postdocs (53%, $n = 16$) [$\chi^2_{(3,\ n = 146)} = 10.9$, $P = 0.012$]. There were no significant differences in academic respondents' motivations to communicate with nonexperts or nonscientists [$\chi^2_{(3,\ n = 146)} = 1.75$, $P = 0.63$], scientists outside their field [$\chi^2_{(3,\ n = 146)} = 4.6$, $P = 0.20$], or policymakers [$\chi^2_{(3,\ n = 146)} = 2.7$, $P = 0.44$].

Confidence in and utility of science communication skills

Next, respondents were asked to retrospectively rank how confident they were in their ability to communicate science before and after taking the ASC course on a 9-point scale (1 being not at all confident and 9 being very confident). All respondents reported a significant increase in self-reported confidence levels after taking the course (median of 8, mean of 7.8, standard deviation [SD] of 0.98 versus median of 5, mean of 5.4, SD of 1.57; $P < 0.0001$). When comparing confidence levels across academic groups, all groups experienced a significant increase in self-reported confidence levels after taking the course, but there were no between-group differences in pre- or postcourse confidence levels (Fig. 3). Graduate students, postdoctoral fellows, and staff and others had a 3.0 change in median baseline confidence levels, compared to faculty, who reported a 2.0 change (Table S1). Respondents were also asked to retrospectively estimate how much time they spent communicating scientific topics to nonexpert audiences both before and after participating in the ASC course (Fig. 4). Prior to taking the ASC course, 51% ($n = 86$) of respondents indicated that they engaged in science communication with nonexperts sometimes (5 to 20 h/year) or often (21+ h/year). Following the course, this proportion significantly increased to 77% ($n = 128$) of respondents ($P < 0.0001$). Graduate students and postdoctoral fellows were significantly more likely to engage in science communication following the course (36% of graduate students, $n = 22$ versus 72%, $n = 39$ [$P = 0.0018$]; 40% of postdoc fellows, n ==12 versus 77%, $n = 23$ [$P = 0.0082$]), compared to faculty (70%, $n = 14$ versus 80%, $n = 16$; $P = 0.72$) and staff and other respondents (64%, $n = 27$ versus 81%, $n = 34$; $P = 0.14$).

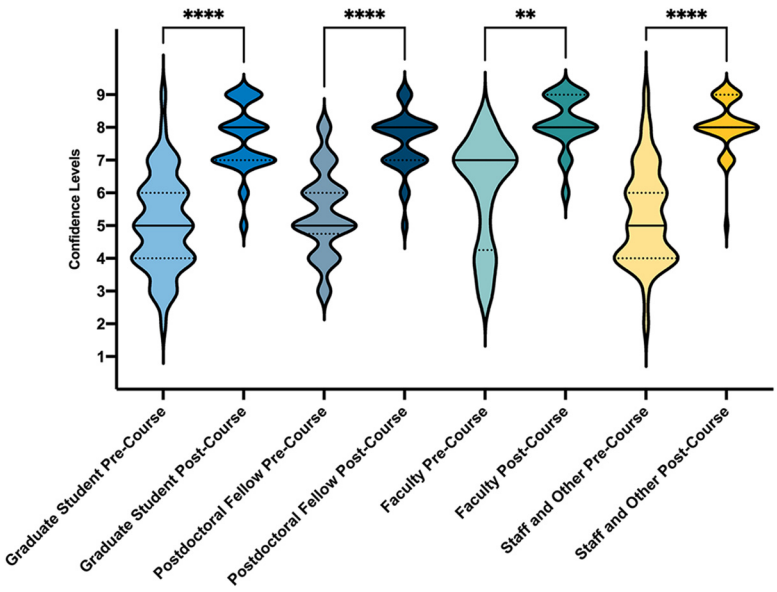

FIG 3. Comparison of respondents self-confidence in science communication skills by academic role. Violin plot represents the distribution of respondents' self-reported pre- and postcourse confidence on a scale of 1 to 9. Solid lines represent the median, dotted lines represent the first and third quartiles. ****, $P < 0.0001$; **, $P < 0.001$.

Professional development

Finally, respondents were asked to describe the impact of the ASC course on their professional development. More than 70% of respondents indicated that by participating in the course they were able to accomplish a professional (71%, $n = 119$), educational (83%, $n = 139$), or personal (92%, $n = 153$) goal (Fig. 5A). Eighty-one percent ($n = 135$) of respondents highlighted their participation in the ASC course on their resume or CV (Fig. 5B), while 26% of respondents ($n = 43$) received recognition at work or school for completing the course (Fig. 5C).

Open-ended responses

Respondents had the option to provide open-ended comments if they indicated that the ASC course helped them become more involved in science outreach, strengthen their communication skills, or achieve a personal or professional goal (Text S1). From these responses, three major themes of increased confidence, professional development, and audience engagement emerged.

Respondents spoke about taking the ASC course to increase their confidence in communicating science to others. In particular, the course enhanced their knowledge about science communication and presentation skills. They also mentioned learning new skills and techniques for conveying scientific concepts, such as avoiding jargon, using analogies, storytelling, and making the topic relatable and understandable to a nonexpert audience. One respondent remarked: "I felt more comfortable communicating my science, so I was more willing to participate in outreach projects." Another respondent stated: "I was able to present myself as a more confident speaker. I was

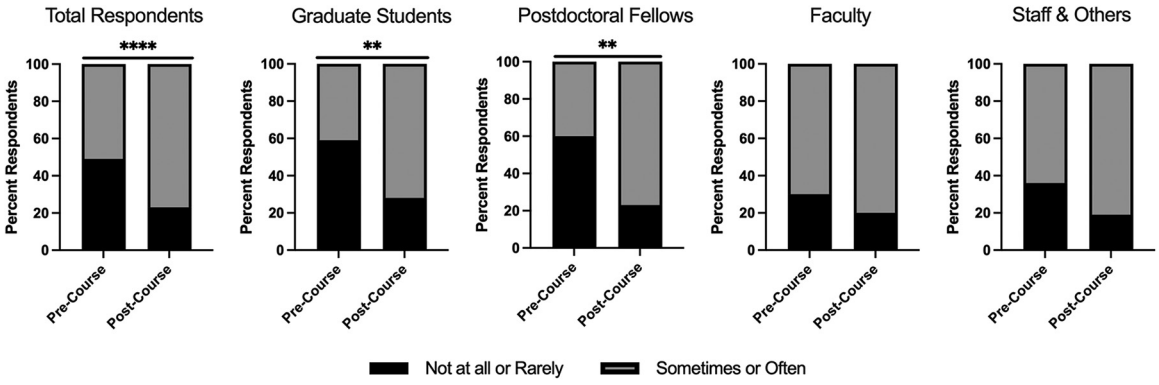

FIG 4. Comparison of pre- and postcourse public engagement activity. Respondents were asked to rank how often they engaged with the public before taking the course and after taking the course. The data were analyzed based on all responses as well as by academic career status. ****, $P < 0.0001$; **, $P < 0.001$.

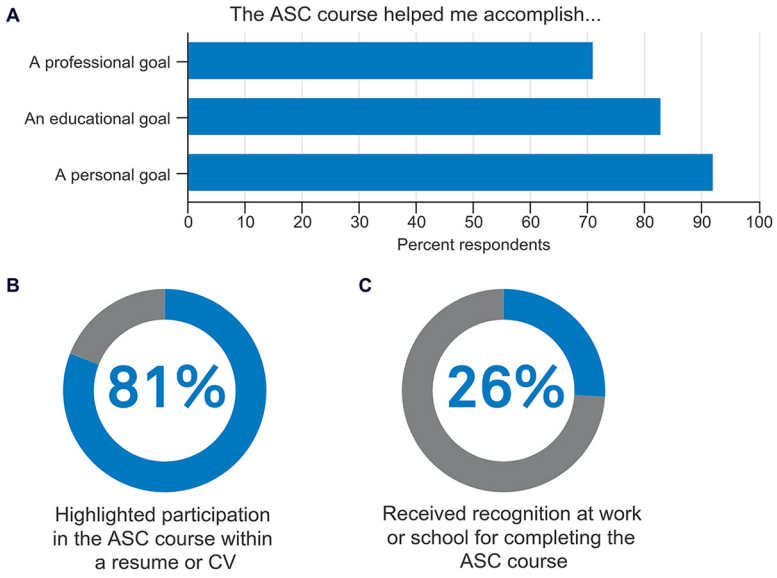

FIG 5. Impact of the course on participants' personal and professional development goals. (A) Proportion of respondents who agreed with each statement as it related to the impact of the course on helping them achieve a professional, educational, or personal goal. (B) Proportion of respondents who reported that they have included their completion of this course on the resume or CV. (C) Proportion of respondents who reported that they have received some sort of recognition from their institution or employer for completing this course.

able to improve the flow of my research presentations, which made it easier to explain and easier for the audience to connect. Incorporating the things I learned [from the] ASC program, I was able to successfully participate in multiple oral research competitions and once represented my university."

Respondents also spoke about achieving professional goals after completing the ASC course. Some reported career advancement through new jobs or positions, acceptance into graduate school, and participation in a continuing education certificate program. One respondent noted that: "The course helped to shape my CV toward a career shift which in the end worked out for me. Now I work as program manager and science communicator at the national research funding agency of my country." Other respondents indicated that the ASC course enhanced their teaching and mentorship skills across multiple levels. One respondent shared that, "Personally, I feel I have a stronger understanding of how to talk to various audiences, and this helps me with my teaching (undergraduate-level biology)." Another stated that, "I feel my own communication skills in the classroom improved by considering my audience and their goals for taking my courses."

In addition, respondents indicated that the course influenced their decision to participate in public engagement activities. "The course gave me confidence to deliver more effective talks, which will be a major benefit in my academic job search. In addition to developing my professional skills, the course inspired me to pursue more outreach and to talk about science communication in my daily life," said one respondent. Another shared the types of activities that they participated in following the course, stating: "I volunteered to give a talk at our local library. . .[and] I also started a blog on Medium communicating scientific ideas to a nonscience audience."

Finally, respondents stated that the course prepared them to speak with other scientists, family and friends, and nonexpert audiences by acknowledging the audiences' perspectives. One respondent remarked: "I believe it is important for a scientist to be able to engage the public on their work in an effort to rebuild the trust between the public and scientists that has been deteriorating in recent decades. My goal has been to offer a friendly face that a nonscientist can feel familiar [or] comfortable with while simultaneously being recognized as a scientist. I feel this course helped me further this goal."

DISCUSSION

While there is a critical need for increased scientific literacy, one of the major limiting factors is the number of scientists who make engaging with the public a priority. Several barriers prevent scientists from participating in outreach activities, ranging from the personal (e.g., a lack of time) to organizational and institutional (e.g., lack of professional incentives or lack of institutional support) (15–18). Scientists also commonly cite a lack of formal training in science outreach and communication skills as another barrier (14, 20–24). Science communication courses geared toward nonexpert audiences are not necessarily new; examples of courses, workshops, or other training activities have existed for several decades (14). These programs, often stand-alone courses at a single academic institution, are traditionally

underresourced, making it impossible for them to have an impact at the scope and scale desired. The ASBMB's ASC course was developed to address these barriers by providing broader access to formal science communication training, regardless of career stage, employment sector, or geographic location (19). For the past several years, we have used informal postcourse surveys to iteratively design and improve the course content. However, this was the first formal survey to evaluate the impact of science communication training on the ASC course participants. Analyses of the survey responses demonstrate that the ASC course increases participants' confidence in their science communication skills and motivates them to participate in outreach and communication activities, regardless of career stage.

Data-driven perspectives surrounding the implementation, evaluation, and outcomes of science communication training programs that focus on nonexpert audiences remain limited. This makes it difficult to determine if and how science communication training programs are meeting course objectives or goals. There are inherent challenges in describing and evaluating what is considered effective science communication, across various audiences. By using pre- and postcourse video analyses scored by nonexperts, Capers and colleagues found that science communication training may not initially translate to effective communication skills (25). Rather, they posited that real-world, iterative practice engaging with nonexpert audiences may be essential to developing such skills. To this end, we recognized that it would be difficult, and perhaps even limiting, to attempt to directly assess ASC students' ability to communicate effectively with nonexpert audiences. Instead, we focused on how participants have changed their self-perception and behaviors related to communicating science and the impacts it may have on their professional development. Put simply, our data are encouraging: scientists are engaging with nonexperts with a greater frequency after completing the course. This suggests that scientists are seeking opportunities to further develop their science communication skills through iterative practice. Moreover, they feel more confident in their science communication skills, a common finding in evaluations of other science communication courses (26–28). A sense of confidence or self-efficacy in participants' science communication skills may lead to increased or sustained public engagement efforts, drawing on social cognitive theory (29). We observed this in our sample, as graduate students and postdoctoral fellows were significantly more confident in their communication skills and were more likely to engage with nonexperts following the course. These findings were echoed in participants' qualitative responses, as confidence emerged as a key theme around science outreach. More work is needed to explore the factors that underpin science communication behaviors and will be essential to scalable and sustainable public engagement.

Although the ASC course is designed to promote dialogues between scientists and nonexperts, there are professional benefits associated with science communication training, in general (30). The ability to communicate effectively with a variety of audiences is a valued skill in any work environment, but it is particularly helpful within academic contexts, where effective communication is a central component of research, teaching, mentoring, and professional networking. Both the quantitative and qualitative data presented here suggest that the course provides tangible professional benefits, which differ by career stage and/or career type. In particular, trainees leveraged their participation in the course as a distinguishing factor within applications for graduate school or employment, whereas faculty were more likely to utilize it for advancement or promotional purposes. The qualitative data suggested that this course also supports individuals who are interested in pursuing careers centered around public engagement. This is of particular interest, as scientists who have expertise in public engagement will be an integral component of developing scalable and sustainable infrastructure related to scientific literacy. As the professionalization of science outreach and communication becomes more commonplace within the scientific enterprise, academic institutions that offer science communication training programs may have a competitive advantage in the recruitment of students, faculty, and staff, compared to those that fail to recognize the need for these types of programs.

It is important to note that there are several limitations to this study. First, this was a retrospective survey which included participants who completed the ASC course in 2015 through 2020. Because of this broad time frame, the contact information we had for participants who took the course in 2015 to 2018 may have been out of date, or interest in participating in the survey may have waned. These factors may have contributed to a reduced response rate. Many of the survey items relied on retrospective, self-reporting, which may have been subject to recall bias, depending on when participants completed the course. In addition, there is the potential for survey order bias based on the placement of questions and qualitative free-response prompts. Individuals who completed the survey may have also felt inclined to respond to questions in a particular way due to social desirability bias, based on what they believe a favorable response might be. Based on these factors, estimates of science communication activity and/or self-reported gains in confidence may have been exaggerated. Another limitation is that we were unable to capture more nuanced information about individuals in the staff and others category. This is particularly relevant as staff play important roles in supporting and conducting public engagement within academic institutions (20). Also, there was not an option to identify as an undergraduate student, so course participants who fell into this category may have selected the staff or others options.

As the ASC course embarks upon its 8th year, we are updating the curricula to better meet the needs of both course participants and the nonexpert audiences they may encounter. We are emphasizing the importance of inclusive science communication practices throughout each of the lectures, homework assignments, and supplemental content, so that participants can explore how science communication can promote or hinder trust, belonging, understanding, or

appreciation of science in different cultural contexts (31). The updated course will also contain additional content that helps participants identify and address misinformation. Based on course feedback, we will also incorporate supplemental content related to specific topics, such as science policy and community-responsive engagement. Finally, we plan to integrate a formal course evaluation process with pre- and post-course surveys so that we continue to monitor the long-term impacts and outcomes from this course.

It is clear that our contemporary world will continue to present scientific and biomedical challenges that threaten societal progress without an increased emphasis on scientific literacy. We must continue to develop educational methods that enable the scientific community to meet nonexperts where they are to bridge divides, promote trust, (re)build relationships, spark curiosity, welcome participation, and develop mutual learning and appreciation. By evaluating the ASBMB's ASC course, we have found that science communication training may foster more frequent and sustained public engagement. It is our hope that the ASC course serves as an exemplar model for other institutions, funders, scientific societies, or organizations as they collectively work to address scientific literacy.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.2 MB.

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Concept and design, all authors; Acquisition, analysis, or interpretation of data, C.M.S., J.S.P., A.J.H., E. Li, N.C.W.; Drafting of the manuscript: C.M.S., J.S.P., A.J.H., M.R.-G., M.D.K., J.T.T., N.C.W.; Critical revision of the manuscript for important intellectual content, all authors; Statistical analysis, N.C.W.; Administrative, technical, or material support, N.C.W.; Supervision, N.C.W.

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