Analysis of Inclusivity of Published Science Communication Curricula for Scientists and STEM Students

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ABSTRACT

There has been an increased push for science, technology, engineering, and mathematics (STEM) students and scientists to be trained in science communication. Science communication researchers have outlined various models of how scientists interact with nonscientists—including deficit, dialogue, and inclusive approaches. We wanted to analyze whether published science communication curricula for STEM students and scientists exhibit features of inclusive science communication. We analyzed $n = 81$ published science communication trainings. We found an increase in such publications over the past two decades. We coded the trainings according to the science communication model they most closely follow, finding 40.7% deficit, 39.5% dialogue, and 19.8% inclusive. Trainings for STEM undergraduates were the least likely to provide training in the inclusive model. Finally, only 27.2% of publications included evaluation of the efficacy of the curriculum using an external scale or framework. These findings present opportunities: while it is positive that there are more published science communication curricula, science education and communication researchers should develop and publish more-inclusive science communication trainings for STEM students. Additionally, undergraduate students can and should begin their training in science communication with a focus on inclusivity not deficits. Finally, science education researchers should develop more standards for evaluating the efficacy of inclusive science communication training.

INTRODUCTION

There have been calls for science, technology, engineering, and mathematics (STEM) students to be trained in science communication (Brownell *et al.*, 2013b; Bankston and McDowell, 2018; Dahm *et al.*, 2019), including *Vision and Change* listing the "ability to communicate and collaborate with other disciplines" as a core competency and disciplinary practice for undergraduate biology students American Association for the Advancement of Science, 2011). However, these calls do not generally explicitly reference inclusive science communication, which is a growing movement that centers diversity, equity, and inclusion in science communication (Canfield *et al.*, 2020; Canfield and Menezes, 2020).

Due to racism, sexism, ableism, and other forms of discrimination, people of many identities have been and continue to be excluded from the scientific enterprise (National Research Council, 2014; Rainey *et al.*, 2018). Science communication in particular has been historically inequitably distributed, with certain people in society having more power in or access to the dialogue around science (Dawson, 2014a, 2014b; Guenther and Joubert, 2017; Canfield *et al.*, 2020; Judd and McKinnon, 2021). Beyond this lack of inclusivity of diverse individuals in science communication, there is also a lack of diverse disciplines. Scientists are not always adequately prepared with the practical skills necessary to co-create knowledge and solutions with experts

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in nonscientific disciplines (Nogueira *et al.*, 2021). Infrequent and ineffective discourse between these groups leads to science communication failures, as evidenced by public responses to the COVID pandemic, the climate change crisis, and other health and environmental issues.

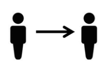
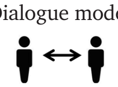
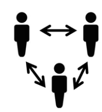
To analyze these issues, it is helpful to assess how science communication researchers consider science communication as well as how scientists and science educators consider science communication, as these are often different individuals in different colleges and departments. Investigating these issues from the perspectives of social science and of STEM, as well as through the lenses of both theory and praxis, is necessary for improvements in science communication outcomes. It is critical for science educators to learn from science communication researchers as we train our STEM students in science communication.

Science Communication Models as Described by Science Communication Researchers

Science communication is "organized, explicit, and intended actions that aim to communicate scientific knowledge, methodology, processes, or practices" (Horst *et al.*, 2016, p. 883). This can include communication about science between anyone, both scientists and nonscientists. Science communication researchers describe multiple theoretical models (see Table 1) for different ways in which scientists interact with nonscientists, sometimes referred to as "the public," regarding science. Secko and colleagues synthesized these models in 2013 (Secko *et al.*, 2013), grouping them into "traditional" models that value science as the most important form of knowledge and focus on transmitting scientific knowledge to audiences. This model contrasts with "nontraditional" models that value knowledge outside science and focus on presenting science tied to particular contexts. The traditional models focus more on science literacy and passive understanding on the part of the public. The nontraditional models encourage two-way dialogue and debate as science is applied to diverse contexts. Kappel and Jon Holmen described these models as the dissemination paradigm versus the public participation paradigm (Kappel and Jon Holmen, 2019). Other scholars have split these two main approaches into three or four categories. In 2003, Lewenstein outlined four models: deficit, contextual, lay expertise, and public participation (Lewenstein, 2003); in 2009, Brossard and Lewenstein further refined these four models but renamed the deficit model as the science literacy model (Brossard and Lewenstein, 2009). In 2008, Trench analyzed various science communication models, identifying three base models: dissemination/deficit, dialogue, and conversations/participation (Trench, 2008). In 2017, Akin and Scheufele outlined three models: the deficit model, the dialogue model, and the contextual model (Akin and Scheufele, 2017). Their definition of communication in context aligns with Lewenstein's public participation model. In 2020, Schmid-Petri and Burger outlined three levels as well: the early focus on increasing science literacy via the deficit model; newer models that are more complex and focus on interacting with society, including the dialogue and participation models; and finally, a desired network-oriented model that involves social network approaches in science communication (Schmid-Petri and Burger, 2020).

Recently, there has been a push to explicitly combat exclusionary culture in science via what is termed inclusive science communication (Canfield *et al.*, 2020; Canfield and Menezes, 2020), which "leverages multiple science communication models (Lewenstein, 2003), including contextual (e.g., culturally-responsive design, per Calabrese Barton and Tan, 2010), lay expertise (e.g., multiple ways of knowing, per Delgado Bernal, 2002), and public participation (e.g., co-creation and collaborative design, per Shirk *et al.*, 2012)" (Canfield *et al.*, 2020, p. 2). Thus, while the term "inclusive science communication" is newer, it is premised on models that have existed in the science communication literature for the last two decades.

TABLE 1. Description of the three science models used in this paper and their derivation from various models in the literature[a]

<table>
<tr><th colspan="13">Models in the science communication literature (split into two, three, or four models)</th></tr>
<tr><td>Secko et al., 2013</td><td colspan="6">Traditional</td><td colspan="6">Nontraditional</td></tr>
<tr><td>Kappel and Jon Holmen, 2019</td><td colspan="6">Dissemination paradigm</td><td colspan="6">Public participation paradigm</td></tr>
<tr><td>Trench, 2008</td><td colspan="4">Dissemination/deficit</td><td colspan="4">Dialogue</td><td colspan="4">Conversations/participation</td></tr>
<tr><td>Akin and Scheufele, 2017</td><td colspan="4">Deficit</td><td colspan="4">Dialogue</td><td colspan="4">Contextual</td></tr>
<tr><td>Schmid-Petri and Burger, 2020</td><td colspan="4">Science literacy</td><td colspan="4">Dialogue and participation</td><td colspan="4">Network-oriented</td></tr>
<tr><td>Brossard and Lewenstein, 2009</td><td colspan="3">Science literacy</td><td colspan="3">Contextual</td><td colspan="3">Lay expertise</td><td colspan="3">Public participation</td></tr>
<tr><th colspan="13">Synthesized into the three models used in this paper</th></tr>
<tr><td></td><td colspan="4">Deficit model</td><td colspan="4">Dialogue model</td><td colspan="4">Inclusive model</td></tr>
<tr><td>Visual depiction</td><td colspan="4">
Unidirectional</td><td colspan="4">
Bidirectional</td><td colspan="4">
Network</td></tr>
<tr><td>Ideological associations</td><td colspan="4">Scientism</td><td colspan="4">Pragmatism</td><td colspan="4">Relativism, deliberation, shared decision-making</td></tr>
<tr><td>What the public is doing</td><td colspan="4">Public understanding of science; science literacy</td><td colspan="4">Public engagement with science</td><td colspan="4">Public participation in science</td></tr>
</table>

[a]While we synthesized down to three models, some science communication researchers describe two, three, or four models, all on a continuum from more deficit-based to more inclusive.

The application of these words and what exactly they imply in the practical rather than theoretical context differs; for example, in 2017, a group of ecologists discussing problems and solutions in invasion biology used only deficit and dialogue models (Courchamp *et al.*, 2017), citing Nisbet and Scheufele's 2009 paper (Nisbet and Scheufele, 2009). However, their 2017 description of the dialogue model describes society as contributors to knowledge and is more in line with Lewenstein's (2003) lay expertise or even public participation models. We posit that, while the exact language or description of the model is valuable, the primary takeaway is that science communication researchers are highlighting the benefits of moving away from traditional one-way models toward models that promote multiple ways of knowing to solve problems that intersect science and society.

Scientists' Views of Science Communication

Several studies have begun to analyze how scientists themselves perceive science communication and public engagement. For instance, in 2019, Rose and colleagues conducted a census of 6242 science faculty at land-grant universities across the United States regarding science communication (Rose *et al.*, 2020). The survey concluded that many of these scientists strongly approved of participating in science communication activities aimed toward increasing public engagement and trust in the scientific community. Furthermore, a greater majority of these scientists understood the importance of nontraditional science communication and the objectives of public engagement. However, other studies using large-scale surveys have shown that scientists' seniority, as well as their attitudes toward public communication activities, impacted the amount of time they engaged in such activities (Dudo, 2012; Dudo *et al.*, 2018). Additionally, scientists valued communication when its goal was to defend science from misinformation and educate the public; however, they did not prioritize communication when its goal was to build trust and resonance with the public (Dudo and Besley, 2016).

These gaps in how scientists perceive and prioritize science communication may derive from how they are being trained. A study using semistructured interviews of $n = 32$ science communication trainers highlighted that training typically emphasizes technical communication skills rather than emphasizing inclusivity (Dudo *et al.*, 2021). The deficit model has been criticized for being ineffective, overly simplistic, and inequitable (Suldovsky, 2016), but it remains persistent in science communication training and practice (Besley and Tanner, 2011). Clearly, there are opportunities for growth in how scientists are trained in science communication to help them develop proficiency in a broader range of communication skills.

Analysis of the Literature: Assessment of Published Science Communication Curricula for STEM Students and Scientists

We hypothesized that a possible reason that scientists are not engaging in more-inclusive, interdisciplinary, network-based models of science communication (whether it is called a public participation model, contextual model, inclusive science communication, or otherwise) is that published science communication training and education for scientists is still focused on older, traditional models. Science educators are integrating science communication training into curricula for STEM students and scientists. As these science educators seek to be evidenced based and rely on peer-reviewed and published methodologies for science communication education, they may be recapitulating non-inclusive science communication approaches if current published curricula do not provide training in inclusive science communication. Such training would not include teaching scientists to value building trust and relationships that enable coproduction of knowledge with nonscientists, nor would the training be giving scientists the skills to do this. Specifically, our research questions were as follows:

RQ1: To what extent do published science communication curricula provide training in skills that exhibit the features of previously described inclusive science communication models?

RQ2: Has there been a change in the inclusivity of skills taught in published science communication trainings over time?

RQ3: Do the trainings that include evaluations of their efficacy tend to be those that teach skills of inclusive science communication?

To answer these questions about the inclusivity of published science communication curricula, we performed a literature search of published science communication trainings for undergraduate STEM students, graduate STEM students, and scientists. We then coded these trainings as providing training in the skills of a deficit, dialogue, or inclusive model of science communication in order to assess the state of the published science communication curricula currently available for STEM students and scientists. Analyzing the data according to group being trained is insightful, because we wanted to assess whether the field is considering certain skills as "prerequisite" for other skills or whether different student populations are being trained in different skills. There have been unique calls for providing better professional development and communication training for undergraduate students (American Association for the Advancement of Science, 2011), graduate students (Ganapati and Ritchie, 2021), and scientists (Bankston and McDowell, 2018), and these calls may be received, interpreted, and operationalized differently by different pedagogical cultures. Warren and colleagues have discussed differences between science communication preparation that may occur for scientists versus graduate students (Warren *et al.*, 2007), and Gerecke has commented on the unique science communication training needs of undergraduates compared with researchers like graduate students or scientists (Gerecke, 2019). This provides a further rationale for exploring differences between the curricula that are published for these different groups. We also assessed the timings of these publications as well as whether the publications included information on evaluation.

METHODS

Literature Search

We performed a literature search of PubMed, ERIC (Education Resources Information Center), and Web of Science as well as common science education journals (*Journal of Microbiology and Biology Education*, *CBE—Life Sciences Education*, *Journal of Research in Science Teaching*, *Journal of Chemical Education*, etc.) using the search terms "science communication", "outreach", and "public engagement" coupled with "training", "curriculum", "course", "education", "workshop", or "program".

TABLE 2. Codebook used to categorize science communication trainings as using a deficit, dialogue, or inclusive model[a]

	Deficit model	Dialogue model	Inclusive model
What the students/scientists are being taught to communicate about	Settled science	Science including uncertainties	Science plus ethical, regulatory, sociological, and political considerations; recognizing cultural funds of knowledge
How the students/scientists are being taught to perceive their audience	A monolithic public (e.g., "the general public," "a lay audience")	Many "publics"—focus on targeting a unique audience	Focus on diversity of audience both in terms of expertise/ discipline but also in terms of identity, culture, etc.
How the students/scientists are being taught to communicate	Skills such as: – one-way communication – removing jargon for a lay audience – producing communication only for scientists in their own field	Skills such as: – two-way communication and receiving feedback on their communication from audiences – targeting unique, specific audiences	Skills such as: – explicitly recognizing the valuable perspectives of those from diverse backgrounds (e.g., Indigenous scientists) – valuing interdisciplinarity; working with those outside their own scientific fields to discuss or solve an issue

[a]Each paper was analyzed in terms of the three elements described in the three rows.

All the search words were used in combination to find a diverse and comprehensive, but not exhaustive, set of trainings offered to scientists.

Once we had located papers using the search terms and science education journals, an initial read through of the papers was done to ensure they met certain criteria. Criteria included the intended audience of the training, the purpose, the location of the training, and the publication date. We focused on papers that were training STEM undergraduate students, graduate students, or scientists themselves in science communication skills. We excluded papers focused on training health professions students in communication skills, as these papers included patient-centric interpersonal communication skills and not just pure science communication. Because we were coding papers based on how science communication addressed issues of intercultural diversity and inclusion, we excluded papers from outside the United States, because we did not want to misconstrue the cultural approaches of other countries. Additionally, we would not have been able to collect a representative data set, because some of these papers may not have been written in English. Finally, we did not include any papers published before the year 2000, because inclusive/public participation models of science communication were not described in the science communication literature until the early 2000s. We ended the literature search in February 2022.

The main limitations of our data set and analysis are twofold: first, not all science communication training and curricula are published—many reside in syllabi and courses that are not publicly accessible; second, the exact nuance of a science communication training cannot always be discerned from the publication, and thus we must infer the main approach from the information provided in the publication. However, the published papers do provide an overview of the approach and goals of the courses/trainings and the skills they teach.

Coding: Models

We coded the papers according to three models—deficit, dialogue, and inclusive—synthesized from the various models described in the *Introduction* (Tables 1 and 2). The codebook (Table 2) was developed a priori using a deductive method based on the science communication models described earlier. While different science communication researchers may have described two, three, or four models of science communication, these were all on a continuum from some sort of deficit-based model to a more-inclusive, participatory model (Table 1). We decided to use three models, as this provided a way to include the well-described deficit and dialogue models as well as an ideal inclusive/participatory model. Three codes versus four promoted more accuracy, as this provided two extremes as well as something in the middle. In a four-code setup, parsing between two intermediate levels would have created difficulty maintaining interrater reliability. As described earlier, the term "inclusive science communication" is growing; it draws on models like public participation (Canfield *et al*., 2020). We defined "inclusive" as promoting diversity of perspectives and identities, as well as diversity of experiences and expertise (e.g., encouraging interdisciplinarity and scientists working with those of different backgrounds). Metcalfe has used these three models to assess the state of science communication programs (Metcalfe, 2019); we were using a similar approach to assess the state of science communication trainings. We selected three key features of each model—what the students/ scientists are being taught to communicate about, how they are being taught to consider their audience, and how they are being taught to communicate—to guide our coding (Table 2).

We coded the papers based on the features of the three models that they were teaching, based on the information that was included in the main text of the published articles. Thus, a skill like removing jargon for unidirectional communication from scientists to a monolithic public was considered a feature of the deficit model. A skill like considering and targeting the concerns of more unique and specific audiences was considered a feature of the dialogue model. A skill like connecting with the community or experts in nonscientific disciplines and learning from those with diverse expertise was considered a feature of the inclusive model. However, we recognize that a limitation of our study is that we are interpreting the approach and focus of the curricula only from what is evident in the publications. We cannot discern the motive of the instructors/authors or exactly what types of conversations and discussions may have occurred in class. Thus, papers coded as "deficit" or "dialogue" may certainly have included some inclusive elements. We coded based on what we could discern from the publication, which is what readers of the publications would be able to see and replicate as well. Additionally, analysis of the supplemental materials for the papers, which sometimes include examples of student work or further details, may have revealed evidence of different models than what was most evident in the main text of the articles that served as the data for our analysis.

Our codebook (Table 2) focused on three characteristics of each model. For the most part, papers contained characteristics of only one model. When a training contained elements of multiple models, we considered what the main outcome of the training was. For example, if a workshop was training graduate students how to give a talk at a conference, even if there was a mention of ethical considerations of science, because the real goal of the training was one-way communication to other scientists, the paper would have been coded as deficit. If the main goal of a workshop was for STEM students and community members to work together to produce a new product, this participatory co-creation would have been coded as inclusive.

Two coders (R.V. and K.M.) who are authors of this paper analyzed each paper individually and coded it. There was greater than 80% agreement between coders. When there was a discrepancy, the coders discussed the papers and came to a consensus on the coding of each paper.

Two examples of how these discussions of discrepancies occurred are delineated. The difference in coding ranged from opposite sides of the spectrum to being one level off. For example, Coder 1 coded (R.V.) Laursen *et al.* (2007) as an inclusive model, while Coder 2 coded (K.M.) this training as a deficit model.

Coder 1 coded the paper as inclusive, because it had a large focus on diversity and the inclusion of multiple voices. Additionally, there was a co-creation of materials between scientists and teachers. The training was collaborative in nature and emphasized an interdisciplinary partnership:

> Together with BSI staff, each member creates a set of four presentations that includes hands-on activities and that are related to their area of scientific expertise. (Laursen *et al.*, 2007, p. 51)

The training also highly emphasized diversity:

> Within the Science Squad program (one of several run by the BSI), schools are prioritized for Science Squad presentations that have low-income and high-minority student populations. (Laursen *et al.*, 2007, p. 51)

However, Coder 2 initially thought the training fell under the deficit model and coded the paper as deficit, because while it had elements of engagement, it lacked an emphasis on practicing dialogue.

After rereading the paper and discussing the training, the coders came to a consensus that the training fell under the inclusive model because of the high level of engagement by K–12 students and the collaborative nature between teachers and graduate students.

Not every disagreement between coders was as polarizing as the first example. For ENGAGE University of Washington (described in Kuehne *et al.*, 2014), the coders only differed slightly. Coder 1 coded the paper as a dialogue model, while Coder 2 coded the paper as an inclusive model.

Coder 1 coded the paper as a dialogue model, because it taught emerging scientists to effectively communicate through a development of a seminar of their own research for a general audience. The training included key characteristics of the dialogue model, including audience consideration, group discussion, and feedback.

> "In a seminar series, students learn storytelling, public speaking skills, and audience perspectives through presentation of their own research to the general public…Students develop skills in translating their research for general and diverse audiences… Connects members of the public to local research and provides students with opportunities to get feedback." (Kuehne *et al.*, 2014, p. 1230)

Coder 2, however, coded the paper as inclusive, because it included feedback and connected scientists to the local community through an exchange of ideas.

After discussion, the coders decided that the training fell under the dialogue model. While there was engagement with the local community, it lacked key characteristics of the inclusive model such as multiple funds of knowledge. The training fits more appropriately under the dialogue model because of the audience targeting and group discussions.

As an additional check for reliability, another author of the paper coded (R.M.) 10 of the 81 papers using the codebook and came to 100% agreement.

Coding: Evidence of Evaluation

Another analysis of the papers was whether or not they included information evaluating the efficacy of the science communication curricula they described. We coded into one of three levels of evaluation: 1) no measurement of efficacy described; 2) efficacy is internally measured, such as with a nonvalidated scale, grade, rubric, or test; or 3) some sort of externally validated efficacy measurement, such as a scale, rubric, or framework (Table 3). One coder (R.M.) did this coding for the 81 papers; as an additional check for reliability, another author of the paper coded (K.M.) 10 of the 81 papers for the presence and type of evaluation and came to 70% agreement. Coders read the papers with specific attention paid to the methodology sections. If the coder could not find any mention of efficacy measurement in the paper, they assumed no measurement of efficacy (code 1). When a scale or rubric was mentioned and it was not stated that the scale was externally validated, either explicitly stated or otherwise referenced, the coder assumed that the efficacy measurement was non-validated (code 2). Coders confirmed external evaluation (code 3) by looking at the cited framework, survey scale, or rubric.

RESULTS

Literature Search

We found n = 81 published science communication trainings that met our data set requirements. The trainings represented n = 33 programs primarily targeted toward undergraduate

TABLE 3. Codebook used to categorize how science communication trainings were evaluated for efficacy, as described in the published literature

	No evaluation	Internal evaluation	External evaluation
Examples	No evaluation described in published manuscript Only author/teacher overall perceptions of the course, with no data (qualitative or quantitative) listed	Student grades Student comments Course survey (with no validated survey constructs cited) Examples of student work provided	Citation of a survey construct, rubric, or framework that was applied or adapted for course evaluation External evaluator involved

students (Squier *et al.*, 2006; Watson and Lom, 2008; Walton and Baker, 2009; Halverson and Tran, 2010; Cronje *et al.*, 2011; Brownell *et al.*, 2013a; Lemus *et al.*, 2014; Goldina and Weeks, 2014; Whittington *et al.*, 2014; Train and Miyamoto, 2017; Alder, 2018; Aune *et al.*, 2018; Beason-Abmayr and Wilson, 2018; Begley, 2018; Clement *et al.*, 2018; Grzyb *et al.*, 2018; Kimber *et al.*, 2018; Lancor and Schiebel, 2018; Lopes *et al.*, 2018; Mayfield *et al.*, 2018; Mehltretter Drury *et al.*, 2018; Petzold and Dunbar, 2018; Pruneski, 2018; Rauschenbach *et al.*, 2018; Schwingel, 2018; Kothari *et al.*, 2019; Vollbrecht *et al.*, 2019; Hoover *et al.*, 2020; Métris, 2020; Garza *et al.*, 2021; Kelp and Hubbard, 2021; Wack *et al.*, 2021; Wrighting *et al.*, 2021), $n = 34$ programs primarily targeted toward graduate students (Trumbull, 2002; Stamp and O'Brien, 2005; Laursen *et al.*, 2007; Trautmann and Krasny, 2009; Crone *et al.*, 2011; McBride *et al.*, 2011; Webb *et al.*, 2012; Bishop *et al.*, 2014; Goodwin *et al.*, 2014; Kohler *et al.*, 2014; Kuehne *et al.*, 2014; Neeley *et al.*, 2014; National Research Council, 2014; Baker Jones and Seybold, 2016; LaRocca *et al.*, 2016; Rohde *et al.*, 2016; Clarkson *et al.*, 2018; Gruss, 2018; Irizarry-Barreto *et al.*, 2018; Johnson and Fankhauser, 2018; O'Keeffe and Bain, 2018; Ponzio *et al.*, 2018; Rodgers *et al.*, 2018; Smith-Keiling *et al.*, 2018; Gillian-Daniel *et al.*, 2020; Hendrickson *et al.*, 2020; Kompella *et al.*, 2020; Tomat, 2020; Derreth and Wear, 2021), and $n = 14$ programs primarily targeted toward scientists (Osmond *et al.*, 2010; Bang *et al.*, 2010; Mayhew and Hall, 2012; Bik and Goldstein, 2013; Crall *et al.*, 2013; Kuehne *et al.*, 2014; Clark *et al.*, 2016; Greer *et al.*, 2018; Stylinski *et al.*, 2018; Stofer *et al.*, 2019; MacArthur *et al.*, 2020; Benedetti and Crouse, 2021; Lorke *et al.*, 2021; Weber *et al.*, 2021). The papers included in the analysis are included in Supplemental Table 1, along with a short summary of the type of program described in the article.

Results of Coding

Overall, 40.7% ($n = 33/81$) of the trainings were coded as providing training in skills that are features of the deficit model, 39.5% ($n = 32/81$) reflected the dialogue model, and 19.8% ($n = 16/81$) indicated the inclusive model. We have provided examples of how we operationalized our codebook in Supplemental Table 2.

When divided by group being trained, science communication curricula for undergraduates were least likely to provide training in skills necessary for inclusive science communication (Figure 1A). Chi-square analysis comparing each student group to whether or not the curriculum providing training in inclusive science communication skills was significant: χ^2 (1, $N = 81$) = 7.0962, $p = 0.028779$.

More papers have been published regarding science communication training in the past decade than in the decade prior. Interestingly, this burgeoning of new science communication trainings has been in more deficit and dialogue approaches rather than inclusive approaches, as shown in Figure 1B.

Overall, 24.7% (20/81) of published trainings described no evaluation of the efficacy of the training; 48.1% (39/81) of the publications included student grades or some other evaluation intrinsic to the course; and 27.2% (22/81) of the publications included an external evaluation or use of a validated scale (Figure 1C). By Chi square analysis, there was no difference in how the publications in each model provided evidence of evaluation: χ^2 (2, $N = 81$) = 4.9917, $p = 0.288151$.

Overall, we found the following answers to our research questions:

RQ1: To What Extent Do Published Science Communication Curricula Provide Training in Skills That Exhibit the Features of Previously Described Inclusive Science Communication Models? Overall, 40.7% of the trainings were coded as providing training in skills that are features of the deficit model, 39.5% reflected the dialogue model, and 19.8% indicated the inclusive model. While 42.9% of published science communication trainings for scientists provided skills in an inclusive model of science communication, only 9% of published science communication trainings for undergraduate STEM students provided training in these skills.

RQ2: Has There Been a Change in the Inclusivity of Skills Taught in Published Science Communication Trainings over Time? More science communication trainings have been published over time, but they are not becoming proportionately more inclusive in terms of the skills in which they provide training.

RQ3: Do the Trainings That Include Evaluations of Their Efficacy Tend to Be Those That Teach Skills of Inclusive Science Communication? There was no significant correlation between science communication model and whether evaluation of the training's efficacy was included in a publication. Overall, only 27.2% of published science communication curricula present evaluation of efficacy according to an external scale or framework.

Trainings Aligning with Features of the Deficit Model

During the coding process, the two coders notated general activities as well as specific quotes to indicate the model that best described each training. Examples of trainings that provided skills that are features of a deficit model included the following activities:

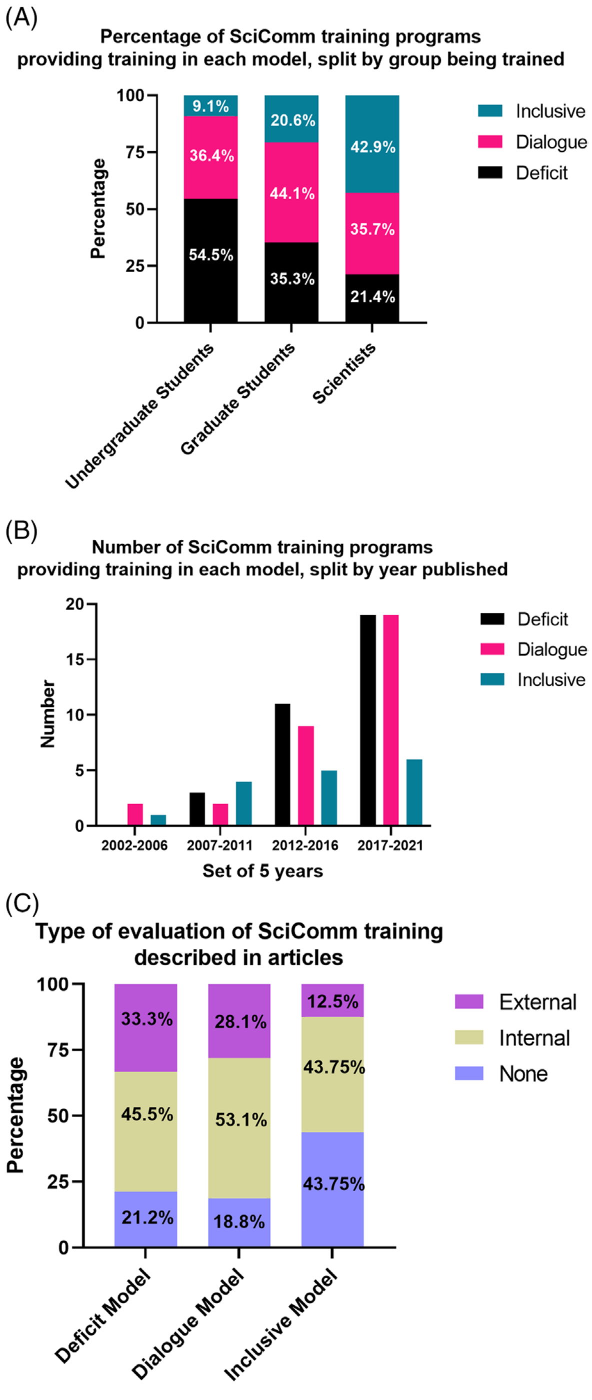


FIGURE 1. Characterization of published science communication training programs promoting deficit, dialogue, and inclusive models. (A) Characterization of programs according to group being trained. Data based on coding of $n = 33$ undergraduate programs, $n = 34$ graduate programs, and $n = 14$ scientist programs. (B) Characterization of programs according to year published. While our literature review examined papers from 2000 onward, papers fitting our criteria were published between 2002 and 2021. These 20 years were split into groups of 5 years for this figure. (C) Analysis of whether programs teaching different models presented information on evaluation of their efficacy. Internal: student grades, perceptions, reflective essays, etc.; external: validated survey, framework, external evaluator, etc.

- Undergraduate biology students taking required curriculum that included disciplinary science writing assignments such as lab reports, group and individual oral presentations, and poster presentations. These trainings did not explicitly encourage dialogue.
- Online writing tool that helped students promote "clear" communication to the public without considering specific or diverse audiences.
- Online lessons to practice oral presentations without technical jargon; these lessons only included unidirectional communication.

In general, these types of trainings did provide students with important baseline science communication skills. Many of these trainings focused on communicating just between scientists, for example:

> Since we stress in this course that the students are preparing themselves to participate in scholarly communication, we take the opportunity of their oral presentations to introduce the concept of audience. We expect them as speakers to recognize the level of their audience and to address them appropriately. (Baker Jones and Seybold, 2016, p. 441)

Other trainings focused on helping students learn how to communicate with the public. However, the "public" was treated as a monolith:

> The posters or pamphlets were to be designed as public awareness materials that would be appropriate for any general audience. (Walton and Baker, 2009, p. 18)

> The main goal of the Decoding Science training was to improve graduate STEM students' ability to communicate their research clearly and compellingly with the general public. The general public was defined as ordinary citizens who were not specialists in the field. (Rodgers *et al.*, 2018, pp. 4–5)

Additionally, other deficit-based trainings aimed to achieve the important goal of "public understanding of science" but did not explicitly mention public engagement with or participation in science:

> Science communication is an important aspect of this framework and should convey how a science idea meets the needs of the scientific community and increases public understanding of scientific awareness, understanding, literacy, and culture. Yet a variety of factors, including an audience's lack of understanding of the nature of science, makes clear communication on science issues difficult. (Aune *et al.*, 2018, p. 1)

Trainings Aligning with Features of the Dialogue Model

Examples of trainings that provided skills that are features of a dialogue model included the following activities:

- Students creating communication deliverables that consider the unique identity of audiences.
- Graduate students working with K–12 science instructors to develop a greater understanding of diversity when communicating with nonscientists.
- Students engaging with diverse public audiences in dialogue after presenting scientific topics.

Papers that were coded as providing training in a dialogue model began to encourage students to think about specific audiences within or outside the sciences, rather than purely "scientist" and "nonscientist" audiences:

> Students designed their presentations and the manner in which the presentations were conducted to reflect the potential audience. For example, the Science Café event "How can we see colors?" was designed for a 5th-grade level audience. Therefore the presentation was composed of many interactive activities, with lots of questions and prizes to engage and maintain student interest. "Nutrition in 2012" was geared toward families, adults, and children. To provide useful information to adults, while maintaining the interest of children, students used PowerPoint presentations, handouts, and a cooking demo where children in the audience were invited to help prepare a healthy meal. (Goldina and Weeks, 2014, p. 15)

These curricula began to encourage students to see science communication as a dialogue and a process, not just pure messaging from the scientist to the audience:

> The course provided classroom instruction, supplemented with improvisation exercises, to reinforce effective science communication skills. Improvisational exercises are natural, intuitive activities that encourage individuals to cooperate with others to achieve a collective goal. The exercises are open-ended and require students to interact directly with each other through a process of collaborative problem-solving. (Ponzio *et al.*, 2018, p. 2)

> To help students elucidate and then transform unfamiliar terms into discourse that is more accessible to non-experts, the course encourages the students to develop and apply explanatory skills through a variety of experiential learning opportunities. One example is the course's focus on being interviewed… To provide a realistic interview experience, the STEM students were paired either with student writers (e.g. from a science journalism class) or with classmates. Formal interviews resulted in popularized articles, which were then shared with the graduate student sources. Both writer and source were given ample opportunity to provide feedback to each other in a one-on-one setting. This feedback focused not only on process (the nature of questions asked and of answers given) but also on science content (scientific terms and analogies) and communication techniques (storytelling structures and types of explanations). (Crone *et al.*, 2011, pp. 294–295)

Trainings Aligning with Features of the Inclusive Model

Examples of trainings that provided training in skills that are characteristic of an inclusive model included the following activities:

- A project that brought lay audiences to science, increasing political participation and social networking around issues valuable to the public.
- Different graduate student workshops that emphasized an interdisciplinary approach to science communication and multiple entry points into science.
- Science-themed meal in collaboration with social scientists provided to the public; the goal was to introduce biodiversity by engaging the public in scientific concepts and brainstorming that would facilitate inclusion of public views and ideas for solutions on issues they value.
- Students collaborating with Indigenous scholars in their local community.

These curricula began to highlight the necessity for interdisciplinarity to promote success, including nonscientists in leadership of the curriculum:

> The team that planned "Tasting the Tree of Life" included Biology faculty members, the Dean of the School of Science, undergraduate Biology majors, and members of Dining Services. (Clement *et al.*, 2018, p. 2)

One paper very explicitly integrated multiple ways of knowing in order to counter Western scientism in its science communication curriculum for STEM students:

> As the foundation for all scientific endeavors—Western or Native Hawaiian—people and relationships were used as a natural and critical starting point for bringing cultural context to science education and communication. Similarly, the significance of place in Native Hawaiian and other traditional knowledge systems and the importance of allowing space for viewing science through a cultural lens were explicitly explored throughout the course. Open class discussion, understanding different cultural approaches to education, and personal interaction with Native Hawaiian scholars and experts were all important elements in students' development of cultural awareness and sensitivity in teaching science, as evidenced by course evaluations. (Lemus *et al.*, 2014, p. 5)

One training for scientists took a very grassroots approach, encouraging equitable community engagement as a means to develop science communication skills:

> [The program] provided comprehensive one-on-one guidance to eight ecologists from eight institutions over four months. [The author] met with each ecologist to learn about their interests, presented ecologists with a list of communities or "focal groups" to engage, and matched them to a group. She initiated contact with focal groups on behalf of each ecologist, learned about the group, and advised ecologists on designing engagement activities. (Weber *et al.*, 2021, p. 4)

Another program combined community-based participation as well as integration of diverse cultural views:

> Our project has two other crucially important goals: (1) to strengthen the capacity of Native communities to improve student learning and achievement and (2) to increase Native undergraduate and graduate student participation in research. In our previous work we have actualized these goals in two ways: through a general process of collaborative praxis that builds the research skills and administrative infrastructure within Indian communities and through a collaborative design process we have been developing and refining. We call this design process community-based design (CBD), the foundation of which rests on the comprehensive participation of community members, including teachers, elders, parents, community experts, researchers, and youth in all aspects of the research, including the conceptions of the problems, project

> design and implementation, and data collection and analysis. (Bang *et al.*, 2010, p. 4)

DISCUSSION

We found that there has been a steady increase in the number of science communication trainings for STEM students and scientists that have been developed and published over the last 20 years. This is an exciting response by the field of science educators to an identified need for scientists to develop their communication skills. However, there are opportunities to increase the inclusivity of these science communication trainings. Ideally, science communication should embrace the more-inclusive end of the spectrum, with a holistic model that incorporates cultural funds of knowledge, values diverse disciplines and expertise, considers social and political contexts, and encourages scientists to coproduce knowledge and solutions with others. Training students with this perspective and the necessary skill set will empower the next generation of scientists to capitalize on their own diverse cultural funds of knowledge as well as promote inclusive science communication practices in their future scientific endeavors.

Most Published Science Communication Trainings for Students Provide Training in Skills That Characterize the Deficit or Dialogue Models

Our study found that many published "science communication" trainings for STEM students simply focused on training students to discuss science with fellow scientists via poster and oral presentations. While these are indeed critical skills, students should not be taught that science communication is limited to these intradisciplinary and formal modalities. It is possible that scientists might value and be most comfortable explaining their work to colleagues rather than other audiences due to factors such as social stigma or lack of institutional incentives (Shugart and Racaniello, 2015). We also found that undergraduates were significantly less likely than graduate students or scientists to receive inclusive science communication training. Practices that reinforce the deficit or dialogue models—such as simply removing jargon—are persistent in undergraduate classrooms, perhaps because educators have been taught that knowledge starts with scientific research and then stems outward, with the student/scientist at the center and the "public" at the periphery (Weerts and Sandman, 2008). We propose that, as educators, we can reframe our thinking so that we are not treating the deficit model as a prerequisite for the other models. Students can learn basic, technical science communication skills while also learning to appreciate diverse viewpoints and perspectives in science communication.

While a paper that mostly included training in skills that are characteristic features of the deficit model would be coded as such, we do not suppose that this means the authors do not value inclusivity in science communication or science education. However, if instructors were to use and recapitulate these published curricula that contain mainly features of the deficit model, science communication training would continue to prioritize only the skills in these more traditional models. Adding an explicit focus on the skills of inclusive science communication—such as eliciting the perspectives of diverse audiences—alongside other important science communication skills—such as removing jargon that would confuse certain audiences—is a potential solution to refine and enhance current science communication trainings. We encourage researchers in this field to develop and publish more trainings that incorporate inclusive elements into foundational science communication skills so that undergraduates and other students are thinking of science communication from an inclusive perspective from the start.

Our findings show a lack of published formal science communication training for STEM undergraduate and graduate students and scientists that provides training in an inclusive approach valuing the diversity of both culture and disciplines. Fortunately, many training programs are moving along the spectrum away from deficit toward dialogue; however, there is still considerable opportunity for future science communication education for scientists and scientists-in-training to become more inclusive. Science educators should develop and publish more-inclusive science communication training, especially for STEM undergraduate students. Additionally, science educators should rely on the work of science communication researchers and the rich literature regarding theoretical models of science communication in order to inform our science communication training of STEM students.

Science Communication Trainings Should Prioritize Inclusivity

Of the papers we coded under the inclusive model, only a few (e.g., Bang *et al.*, 2010; Lemus *et al.*, 2014; Derreth and Wear, 2021) included training explicitly focused on communicating with individuals of different marginalized racial groups. Ignoring these populations means science is missing out on diverse perspectives necessary to solve complex problems (Polk and Diver, 2020). Using an inclusive lens can not only lead to more effective communication (Canfield *et al.*, 2020) but can also shift historical inequities upheld in STEM (Derreth and Wear, 2021). Trainings should help students develop both the worldview and skills necessary to engage in inclusive science communication (Simis *et al.*, 2016).

If instructors teach students how to communicate using an inclusive and interdisciplinary lens, they could encourage students to be boundary spanners within their communities. Boundary spanners are individuals who bridge two communities, such as academics and community groups (Delaine *et al.*, 2015). Because undergraduate students are more diverse than scientists/faculty members (Taylor *et al.*, 2020), students may already have the trust and relationships needed in different communities to facilitate effective communication about socioscientific issues (Nisbet and Scheufele, 2009). Additionally, as boundary spanners, students from diverse groups can bring their communities' knowledge into scientific conversations, providing new perspectives about complex problems. For example, when discussing socioscientific issues, Indigenous students tend to emphasize moral imperatives more than their non-Indigenous peers, composing scientific arguments under a framework that their community values (Balgopal *et al.*, 2016). Undergraduate science communication trainings that follow network/inclusion-based models could better value such cultural funds of knowledge.

Published Science Communication Trainings Lack Evaluation of Efficacy

In terms of evaluating the efficacy of their trainings, while 48.1% (39/81) of publications provided student grades or some other intrinsic evidence of efficacy, only 27.2% (22/81) of the publications included external evaluation of efficacy (via a validated scale, external evaluator, application of a framework, etc.). This provides another area for growth in the field of science communication trainings for STEM students and scientists: There is a need for more external frameworks, scales, and other mechanisms to evaluate the efficacy of the programs developed and published by science communication educators. Assessment of science communication training efficacy is notoriously difficult—and whether trainings show efficacy likely depends on how they are assessed (Rubega *et al.*, 2021). However, many science education researchers have begun to develop scales and frameworks to support evaluation of student science communication skills (Cline *et al.*, 2021; Shivni *et al.*, 2021; Wack *et al.*, 2021), and we encourage further work in this area. In particular, we call for more scales and frameworks to be developed that explicitly evaluate students' skills in inclusive science communication, which is a gap in the literature. One suggestion is building on the inclusive science communication framework of inclusivity, reciprocity, and reflexivity (Canfield and Menezes, 2020) and developing tools to assess students' skills in these areas.

Next Steps for Science Communication Educators

We do view the increase in number of published science communication curricula as a step in the right direction. These works aimed at increasing science literacy and communication skills in STEM students are necessary. Science educators should consider how to add the principles of inclusive science communication to these existing activities. How can we train students to consider inclusion when doing poster and oral presentations? How can diverse perspectives be integrated into activities that are shown to improve student confidence in talking about science? How can we evaluate the efficacy of inclusive science communication trainings? The published papers that exist should not be ignored if they are currently providing training in skills that follow a deficit model; rather, they should be adapted to include more inclusive elements.

Some calls by science educators to include science communication training for junior scientists as a valued component of their other training activities suggest the need for standardized resources and curricula (Bankston and McDowell, 2018). We echo these calls that science communication training should be valued as a critical scientific skill and that published curricula can provide a valuable tool to support the inclusion of this training in STEM curricula. However, if educators use evidence-based, published curricula or resources from others, there should still be the flexibility for students to engage in local science communication and listen to the needs of individuals in their communities.

Overall, we posit that one tool to solve problems facing society—including health and environmental crises, scientists without the communication skills necessary to coproduce knowledge with diverse stakeholders, and lack of inclusion in STEM itself—is to move toward an inclusive model in how we train scientists in science communication. Science educators should develop and publish additional science communication trainings for STEM students and scientists along with ways to evaluate the efficacy of these trainings, so that the community of science education researchers can collectively move toward being inclusive.

The National Academies of Sciences, Engineering, and Medicine's 2017 report entitled *Communicating Science Effectively* includes as one of its five categories that science communication enables scientists to "engage with and consider the perspective of diverse groups when seeking solutions to societal problems" (National Academies of Sciences, Engineering, and Medicine, 2017, p. 18). The other goals of science communication cannot be achieved without this pillar.

Positionality

The corresponding author (N. K.) and other members of the lab have developed and published science communication curricula for STEM undergraduate students; we hope to increase the inclusivity of future curricula developed by our lab. The analysis described in this essay has been useful for us as the lab moves toward more-inclusive science communication training, and we hope that this is useful for other science educators and researchers as well.

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