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RETHINKING Science Communication Education and Training: Towards a Competence Model for Science Communication

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Science communication is at a pivotal stage in its development due to the emergence of digital communication platforms that are not only presenting new opportunities but are also leading to new challenges. In this context, science communicators, who can include scientists, researchers, curators, journalists and other types of content producer, may require new types of preparation and support to engage with multiple audiences, across multiple channels. Despite the increasing need for adequate science communication training, research in the field is sparse and oftentimes refers to single case studies, calling for more comprehensive perspectives on what is needed and what is offered to equip future science communicators with relevant competences to cope with the changing science communication ecosystem. Against this backdrop, this paper takes two approaches, drawing on data from RETHINK, a European project comprising seven countries, Italy, the Netherlands, Poland, Portugal, Serbia, Sweden and the United Kingdom. First, we report on findings from a questionnaire survey completed by 459 science communicators across the seven countries, focusing on how science communicators develop their communication skills, the types of training they have received and the types of training they would like to undertake. Second, we assess exploratory data collected from 13 different science communication degree programs regarding how they seek to embed and consider issues of digital transformation within their curricula. On the basis of both analyses, we will introduce ideas for a competence framework that addresses not only working knowledge and skills but also professional (self-)reflection and the overall mindset and worldviews of students, whilst offering capacity for increased consideration of the role of digital transformation.

Keywords: science communication, training, digital transformation, skills, competencies, public engagement

INTRODUCTION

Science communication is at a pivotal stage in its development. In the so-called knowledge society, science is a core driver of societal development thus emphasizing the importance of science communication for economic growth, societal welfare and political decision making (Kahan et al., 2012). These developments are being further accelerated by digital transformation that has profoundly changed the ways in which science and society interact. In this regard, we have witnessed a tremendous increase in the volume of science communication even if differences in the development of science communication can be identified in different countries (Gascoigne et al., 2020). There is now a sense in which "science communication is at a moment of transition - sometimes even described as a moment of crisis" (Davies et al., 2021, p. 7), whereby science content is communicated by a diversity of actors such as scientists, science journalists, university PR professionals and more (Milani et al., 2019; Weitkamp et al., 2021) and there has been a growth in science PR and contraction of science journalism. In addition, we find a broad range of "new" communicators such as influencers, corporate communicators, activists or political actors who refer to science to make their voices heard in the noisy, fragmented and dynamic networked public sphere (Fähnrich, 2021). The emergence of new players, especially digital communication platforms that determine sociotechnical features such as algorithms which influence the distribution of public communication, presents further opportunities but also challenges for science communication.

These digital communication developments have been debated intensively in different fora and with different foci in recent years. However, there has been relatively little discussion of these changes in the context of science communication training. This is astonishing given that adequate training for those involved in science communication is essential for the quality of science communication in the long term (Baram-Tsabari and Lewenstein, 2017). The question then is how can training contribute to enhance science communication in the context of the digital science communication ecosystem? Moreover, little research has compared training across international (or at least European) contexts, making international differences in approach to coping with issues of the digital transformation within science communication training a relevant field of inquiry.

To address these issues three sub-questions come to the fore:

RQ1: What types of training do science communicators receive in different European countries?

RQ2: Which competencies are required in the changing science communication ecosystem?

RQ3: How well are existing programs across Europe suited to equip science communicators with required competencies?

To respond to these questions, this paper draws on data from the European project RETHINK and takes two approaches. First, we report on findings from a survey completed by 459 science communicators across seven countries (Italy, the Netherlands, Poland, Portugal, Serbia, Sweden and the United Kingdom) focusing on how science communicators develop their communication skills, the types of training they have received and the types of training they would like to undertake. Second, we present exploratory data collected from 13 science communication programs from seven European countries regarding how these seek to embed and consider the digital transformation within their training programs. On the basis of both analyses, this article will conceptually examine whether a multi-level training approach is better suited to prepare science communicators for the steadily changing science communication landscape and will introduce ideas for a competence framework that addresses not only working knowledge and skills but also professional (self-) reflection and the overall mindset of students.

Science Communication Training and Programs

Science communication training equips students with the ability to reflect certain circumstances of communication practices, for example topics they communicate or specific requirements of the platform they use (e.g., interactive features) (Howell and Brossard, 2020). Often, short training courses for scientists and practitioners teach practical communication skills, for example how to use media or how to approach audiences (e.g., Miller et al., 2009; Silva and Bultitude, 2009). In contrast, degree programs in science communication encompass theory and professional development in a more comprehensive approach (Mulder et al., 2008) and therefore can help to provide "a bigger picture" (Turney, 1994).

In both cases, research highlights the need to develop generalizable learning outcomes for science communication, especially with regard to different contexts of information and communicator roles (Baram-Tsabari and Lewenstein, 2017). Frequently, the need to understand societal and media changes is emphasized as these developments are crucial for science-society interactions. Furthermore, science communicators' self-perceptions and an understanding of their roles in the new communication environment can be promoted through reflection on new relationships between science, society and the media (Pieczka, 2002; Baram-Tsabari and Lewenstein, 2017).

Although research on science communication training has been sparse, we acknowledge an increase in interest in both what science communication training comprises and how the quality of science communication training is evaluated (Silva and Bultitude, 2009; Rodgers et al., 2020; Akin et al., 2021; Dudo et al., 2021; Heslop et al., 2021).

Baram-Tsabari and Lewenstein (2017) identify a range of learning goals pertinent to science communication training programs (both short courses and degree programs); they argue for six broad areas in which communicators require training: affective, content knowledge, methods (practical skills), reflective practice, participation and identity. To these we might add an understanding of how people learn, a specific focus on assessing the credibility of information and skills in evaluation (Longnecker and Gondwe, 2014). There is also a strong emphasis on the need for science communicators to understand the audience (e.g., Longnecker and Gondwe, 2014; Longnecker, Forthcoming 2021). These broad categories offer a starting point to assess the training available to science communicators, though to our knowledge there is no comprehensive assessment of whether the training available addresses all of these aspects.

Digital Competences

Given the rapid increase in digital media, it is notable that neither Longnecker and Gondwe (2014) or Baram-Tsabari and Lewenstein (2017) explicitly highlight digital skills within training goals, instead embedding these within other categories. Nor do they address how science communicators' competences might need to expand to cope with the changes and challenges of science communication in the digital media landscape in general, or which competencies are needed for effective communication on these new platforms in everyday practice. Though a variety of training and degree programs do incorporate specific digital skills training, such as podcasting or blogging (Rifkin et al., 2010; Bartle et al., 2011).

In related fields such as journalism or public relations (PR) education we see comparable developments. In this regard, Pieczka (2002) distinguishes three levels of PR expertise that professional communicators need to encompass. Though writing in 2002, Piezcka addressed the rising importance of digital communication. She describes these competences on the basis of observations of communication training. The competence levels include the "picture of the world", the "conceptual frame" and "professional knowledge". Based on her research and observation, Pieczka (2002) describes societal changes due to digitalization and related demands for professional (science) communicators that are mirrored in their "picture of the world". To develop the picture of the world within training thus means to develop the mental models of students and the ways in which they perceive the changing media landscape and how it affects the conditions for the interaction of science and society. The second layer of the competence model refers to specific attitudes and norms that professionals take up to distinguish themselves from non-professionals. For instance, considering ethical standards and being aware of the importance of evaluating science communication would refer to this level of competences. Also being aware of one's and others' roles and related demands and being able to fill these roles are important competences. Moreover, according to Pieczka (2002), communicators need to be equipped with competences and skills to work in the digital world. This encompasses technical knowledge of the media and digital tools or practical skills to transfer communication through different channels. Following Baram-Tsabari and Lewenstein (2017), the will to keep up with new developments displays a dimension in its own which refers to this category. Developing these competences calls for the teaching of models, methods and techniques required in professional science communication. The competence levels developed by Pieczka (2002), and the agile nature of the framework, can be used basis to analyze science communication training.

Science Communication Trainers and Trainees

Research conducted on the perspectives of trainers has tended to focus on those who train scientists in public communication. This research suggests that trainers view scientists and researchers as seeking training to address individual goals (such as enhancing personal skills) and external goals (such as promoting the value of science), rather than communication oriented goals (such as building trust) (Besley et al., 2016). Possibly as a result of this view of trainees' desires, training does not always develop strategic communication skills or assist with creating and prioritizing objectives, often being more skills focused and concentrating on a relatively limited set of implicit objectives, such as increasing knowledge (Besley et al., 2016). Similarly, although trainers recognize the importance of two-way communication, Yuan et al. (2017) found trainers assess scientists as having relatively limited awareness of or interest in two-way communication approaches. As a result, trainers do not integrate these competences consistently in training programs, focusing primarily on the importance of understanding audiences as a means of achieving effective two-way communication. These studies indicate that trainers primarily focus on "professional knowledge" rather than "picture of the world" or "conceptual frames". In the context of the increasing importance of digital media, Yuan et al. (2017) argue that scientists' combined lack of interest and skills in two-way communication suggests few achieve real dialogue with their publics. The presence of educational and information-based goals in science communicators motivations, albeit alongside a desire to create conversations is something we have also identified in previous work (Milani et al., 2020).

Turning to scientists themselves, Altman et al. (2020) found scientists recognizing a need for training, though this was limited to practical skills, such as face-to-face communication and use of plain language, rather than strategic goals (all would be classed as "professional skills"). Similarly, in a study specifically focusing on online science communication, Besley et al. (2015) suggest scientists' value training in the areas of crafting understandable messages and ensuring trustworthiness rather than issues such as framing. Previous studies have suggested that scientists' use of social media for communication can be limited by a lack of knowledge as to how platforms work (Collins et al., 2016). Besley, Dudo and Storksdieck's study extends this to also suggest a perception that communication goals align with ethical goals, and is also an important aspect of scientists' willingness to communicate, which does suggest some interest in the conceptual framing of their activities.

Training Impacts

More recently we have seen increasing research that seeks to quantify, model and scale the impacts of training initiatives (Copple et al., 2020; Rodgers et al., 2020; Akin et al., 2021). Recent research exploring how training contributes to scientists' and researchers' propensity and ability to communicate has suggested mixed results, with inconsistent findings regarding the positive associations between a scientist's training experiences and their ongoing communication intentions (Silva and Bultitude, 2009; Copple et al., 2020). However, Copple et al. (2020) model based on a survey of over 500 scientists working at United States universities found that training can influence willingness to engage by building confidence, contribute to more positive attitudes towards audiences, and that the more training a scientist receives, the more willing they are likely to be to engage. Stylinski et al. (2018) also identified multiple benefits, including that training can assist scientists to build their communication strategies, have more confidence in their abilities, and encourage them to engage more frequently. Research has also identified that communication training can have positive aspects on other areas of a researcher's work, such as teaching and presenting in general (Illingworth and Roop, 2015; Stylinski et al., 2018). However, most research or evaluation of the impact of training has focused on the impacts that trainers or trainees perceive, rather than whether audiences perceive improved communication skills as a result of training (Rubega et al., 2020). Several authors have highlighted the importance of considering all the beneficiaries of training, which includes the audiences who participate in communication activities undertaken by trainees (Rodgers et al., 2018; Rubega et al., 2020).

Training Gaps

In regard to current training provision, a variety of critiques have been made. This includes that training is often too focused on specific communication techniques, as opposed to the broader goals or strategies for communication, which may have longer-term impacts (Besley et al., 2016), and that relatively few trainers are focusing on equality, diversity and inclusion (EDI) topics (Heslop et al., 2021). In the United States and United Kingdom, attendees tend to be self-selecting and lack cultural and ethnic diversity, and whilst trainers may equip trainees with how to communicate, this rarely extends to locating opportunities to communicate (Dudo et al., 2021; Heslop et al., 2021), though there are examples of innovative training programs designed to enable scientists to reach out to underserved audiences (Weber et al., 2021). There is also a recognized need for both further evaluation of the impacts of training, including by specific programs (Dudo et al., 2021), and increased professional recognition for the trainees that are involved (Illingworth and Roop, 2015). Nevertheless, trainers themselves have mixed feelings about accreditation of training programs (Heslop et al., 2021).

However, many of these gaps and criticisms have been drawn by the science communication community itself, rather than reflexive insights of those involved in training, or longitudinal consideration of impacts. Much of the evidence around science communication training has also currently focused on training aimed at scientists and researchers communicating as a part of their career (Miller et al., 2009; Besley et al., 2016; Copple et al., 2020; Akin et al., 2021; Weber et al., 2021), as opposed to those who may be specifically working as science communicators, though a few studies of training in specific contexts, such as informal science learning, do exist (e.g. Walker et al., 2020). There is also a tendency to focus on specific countries, with many studies of science communication training currently emerging from the United States context with few studies that explore training provision in developing countries (Walker et al., 2020) or non-western contexts (Ishihara-Shineha, 2021).

In addition, our knowledge of the overall development of science communication training against the backdrop of the digital transformation is sparse. The same applies to international comparisons of science communication training (Mulder et al., 2008). However, science communicators, which can include scientists, researchers, curators, and journalists but also new types of science related content producers such as influencers, activists, corporate communicators or political actors (Fähnrich 2021), may require new types of preparation and support to engage with multiple audiences, particularly in the context of the digital transformation. The diversification of communicators and new logics of public attention are influencing the working conditions and day to day routines of those involved in science communication and related competences that should be taken up in science communication education and training.

MATERIALS AND METHODS

Survey of Science Communicators

To address the first and second research question - types of training that science communicators have (RQ1), and required competences and training (RQ2)—a survey was conducted in seven countries—Italy, the Netherlands, Poland, Portugal, Serbia, Sweden and the United Kingdom. These countries were selected on the basis of project partners' locations and access to science communication networks and communities within those geographical countries and we recognize the focus is limited to Europe.

The survey aimed to investigate the working practices, motivations and barriers faced by actors communicating science, technology and/or health. It also analyzed the sources they used, how they curate content, and consider the audiences they are working with, as well as the training they had and would like to receive (Milani et al., 2020; Milani et al., 2021). The questionnaire included several questions adapted from previous surveys and studies of scientists, those who enable science to be communicated, such as press officers, as well as science journalists (Royal Society, 2006; TNS-BRMB, 2015). The questions were also informed by a previous scoping study conducted as part of the RETHINK project (Milani et al., 2019).

The questionnaire was developed in Qualtrics, and pilot-tested with 22 respondents. After editing to incorporate feedback from the pilot, the questionnaire was then translated and uploaded to Qualtrics to collate the responses from the seven countries. The final questionnaire was distributed between September and November 2019 via official mailing lists, networks, associations, and societies of journalists, writers, press officers, communication officers, scientists, and public events organizers that communicate science. Snowball sampling was also applied and individuals identified in the scoping study (Milani et al., 2019) were contacted to enrich the diversity of participants. The variety of ways in which participants were recruited means it is not possible to estimate a response rate and any percentages we present should be viewed in the context of the sample size. Univariate and bivariate analysis was conducted using excel and SPSS. The questionnaire received ethical approval from UWE Bristol, and included GDPR compliant consent and information materials.

Exploratory Study of Science Communication Programs

To respond to RQ3—how well are existing programs suited to equip science communicators with required competences?—we used an exploratory approach to analyze the content of 12 science communication programs in seven European countries including Germany, Italy, the Netherlands, the Portugal, Russia, Sweden and the United Kingdom (Fähnrich, 2020). For reasons of comparability, our sample comprised only science communication degree programs offered by universities (undergraduate and graduate level). These academic programs run over a longer period than short course training programs (for instance, usually four semesters at postgraduate level) and are organized in a modular approach.

To explore the content provided in the curricula and to see how the programs addressed demands and challenges of science communicators against the backdrop of the digital transformation, we contacted program managers of 43 programs in the selected countries via e-mail and invited them to take part in an online survey with open and closed questions.

The questionnaire was developed on the basis of the theoretical categories of learning outcome and competence by Baram-Tsabari and Lewenstein (2017) and Pieczka (2002). The focus was on the role of digital media and the ways in which the digital transformation was addressed in the programs. Moreover, we wanted to understand how courses prepare students to adapt their communication to the digital information environments and thus address different levels of competences beyond mere skills. More specifically, we asked about the general orientation of programs towards theoretical or practical skills and about the importance of digital media and related developments in curricula. Furthermore, we were interested in capturing to what extent specific elements of digital media such as diverse audiences and interactivity were captured by programs. Therefore, we presented a list of aspects describing digital media and asked participants for their agreement about the inclusion of these in their programs. Greater detail on how students are trained to cope with developments in digitalization was sought through an open response format.

Different roles for science communicators mentioned in related literature (Pielke, 2007; Fahy and Nisbet, 2011) served as the basis for a question on skills development. Furthermore, the questionnaire sought general program information, such as introduction and validation of courses, number of students graduating per year and common employment fields for graduates. Respondents completed the questionnaire by indicating their position, their disciplinary background, as well as experience and sociodemographic information. Data collection took place in October 2019. We conducted the online survey with the platform "Soscisurvey". Overall, we collected 13 responses from 12 programs from Italy (2), the Netherlands (2), Portugal (3), Russia (2) and the United Kingdom (3). All of these are graduate programs at masters level which require students to already have an academic degree (M.A., N = 3; M. Sc., N = 7; other graduate degrees, N = 3). Programs are taught in English (8) and/or Dutch (2), German (1), Italian (1), Portuguese (3) or Russian (2).

RESULTS

Training, Expectations and Needs of Science Communicators

Of the respondents (total n = 459) to the science communicators' questionnaire, over half were female (59%, n = 272) and 40% (n = 182) were male. The higher response rate from females occurred in most countries, except Poland, where females accounted for 40% (n = 11) of the respondents. The majority of respondents (84%) were under 45 years old; 31% (n = 141) were 35–44 years old, 30% (n = 136) were 25–34 years old, and 3% (n = 12) were 18–24 years old.

When asked about their professional roles, many respondents described themselves as working as press officers or communication officers, freelance communicators or writers, journalists, and/or researchers. The survey also reached actors who might be considered relatively recent additions to the science communication landscape, such as bloggers and social media influencers, activists, illustrators and designers. Eighty five percent (n = 388) of respondents worked for an organization rather than individually. Of these, 52% (n = 202) worked for universities and research centers, 14% (n = 54) for museums and science centers, 10% (n = 40) for non-profit organizations and charities, 6% (n = 23) for media and publishers, 5% (n = 19) worked in the business sector and 3% (n = 12) for professional associations and learned societies. Well over half (63%, n = 74) of the freelance communicators or writers said they work for an organization as well; with universities and research centers being the most common sources of employment.

Turning now to training, we asked respondents how they had developed their communication skills to convey science, technology and/or health topics (**Figure 1**). Almost three quarters of respondents (73%, n = 336) indicated that they had developed their skills through experience in public engagement or communication, whilst watching and learning from others also appeared to be important, with 57% (n = 260) of respondents indicating that they have watched how other people (either professionals or amateurs) communicate with non-specialist audiences. Thirty four percent (n = 156) of respondents also indicated other communicators and/or journalists had informally mentored them. These results combined suggest there is still a strong component of informal training, learning by doing and from others, taking place in science communication as an approach to build competence.

In regard to more formal training, just under half of respondents (48%, n = 221) indicated that they had received training in public engagement or communication, whilst 28% (n = 130) of respondents had or were completing a degree in journalism, media or science communication. A similar number of respondents (31%, n = 143) also indicated that they had consulted resources such as books, handbooks, blogs, and YouTube videos to develop their science communication skills. Finally, 51 (11%) respondents indicated that they had developed

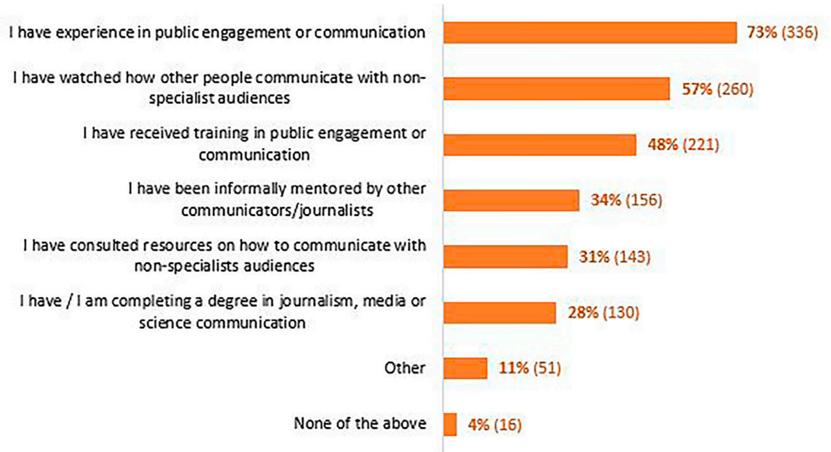

FIGURE 1 | Development of communication competences to convey science, technology and/or health topics. Respondents could select multiple answers.

TABLE 1 | Development of communication competencies to convey science, technology and/or health topics by country. Respondents could select multiple answers. Note: The variety of ways in which participants were recruited means it is not possible to estimate a response rate and any percentages we present should be viewed in the context of the sample size.

	United Kingdom	Netherlands	Sweden	Portugal	Italy	Poland	Serbia
I have experience in public engagement or communication (e.g. writing, public speaking, social media)	98 (80%)	38 (61%)	32 (73%)	75 (86%)	45 (58%)	22 (76%)	16 (64%)
I have watched how other people (either professionals or amateurs) communicate with non-specialist audiences	79 (65%)	27 (43%)	24 (54%)	47 (54%)	31 (40%)	26 (90%)	16 (64%)
I have received training in public engagement or communication (e.g. writing, public speaking, social media)	71 (58%)	20 (32%)	20 (45%)	48 (55%)	39 (51%)	11 (38%)	4 (16%)
I have been informally mentored by other communicators/journalists	47 (38%)	24 (39%)	13 (29%)	26 (30%)	25 (32%)	5 (17%)	10 (40%)
I have consulted resources on how to communicate with non-specialist audiences (e.g. books, handbooks, blogs, YouTube videos.)	45 (37%)	17 (27%)	11 (25%)	32 (37%)	16 (21%)	9 (31%)	6 (24%)
I have/I am completing a degree in journalism, media or science communication	34 (28%)	25 (40%)	12 (27%)	28 (32%)	19 (25%)	4 (14%)	2 (8%)
Other, please specify	16 (13%)	4 (6%)	8 (18%)	7 (8%)	9 (12%)	5 (17%)	0 (0%)
None of the above	7 (6%)	1 (2%)	1 (2%)	3 (3%)	1 (1%)	0 (0%)	3 (12%)

their skills in other ways. Comments in response to this question included that they were self-taught, used networking to develop skills, had built up professional experience or had experience in the disciplines they were communicating. Only 16 respondents said they had completed none of these activities in relation to their skills development.

Examining this question in conjunction with the gender of participants and the country in which they were located, there are some small variations to note. Gender appeared to play very little role in the likelihood of participating in certain types of training. Percentages of women and men developing their skills via experience in public engagement or communication, watching and learning from others, through training in public engagement or communication, and via the consultation of resources were within 1–2% of each other when analyzed. However, more women recorded that they had or were completing a degree in journalism, media or science communication (32%, n = 86 of female respondents compared to 22%, n = 40 of males) and women (35%, n = 95) were also slightly more likely than men (32%, n = 58) to have taken up mentoring.

There also appeared to be some minor differences in terms of training in relation to where communicators were based (**Table 1**). Experience in public engagement or communication was the most common way to increase skills across all countries. However, uptake of formal training, including training in public engagement or communication was more common amongst communicators in Italy (51%, n = 39), Portugal (55%, n = 48) and the United Kingdom (58%, n = 71), whilst completing a degree in journalism, media or science communication was more evident in countries including the Netherlands (40%, n = 25) and Portugal (32%, n = 28). Although the response rate was lower from Serbia, these communicators mainly build their skills via experience (64%, n = 16), watching others (64%, n = 16) and informal mentoring (40%, n = 10) with fewer communicators participating in training (16%, n = 4) or formal degree programs (8%, n = 2).

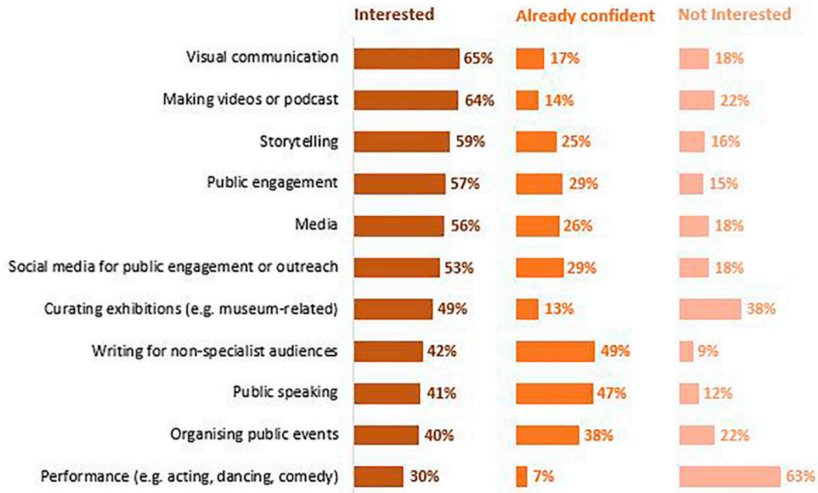

FIGURE 2 | Areas of training in communication and public engagement that respondents would be interested to undertake. Respondents could tick multiple answers.

Although the recording of a degree in journalism, media or science communication was relatively scarce amongst our respondents, the majority of those completing the survey did have a background in science, technology, engineering, math or health. Three quarters (75%, n = 343) of respondents had studied at school, 58% (n = 269) had or were completing an undergraduate degree, 40% (n = 186) had or were studying a postgraduate degree, and 34% (n = 158) were completing a doctorate in one or more of these subjects. Eighteen percent (n = 83) of respondents indicated they were self-taught when it came to science, technology, engineering, math or health.

We asked about the focus of training they had received and 214 respondents completed this question. The most common training areas were: public speaking (66%, n = 142), writing for non-specialists (65%, n = 139), and media training (60%, n = 129). 50% (n = 107) had received public engagement training, with 48% (n = 102) having some form of training in social media, and similarly, just under 100 respondents (48%, n = 98) had training in storytelling. Training in the organization of public events (40%, n = 86), making videos or podcasts (33%, n = 70) and visual communication (31%, n = 67) were also evident, whilst 20% (n = 43) had training in curating exhibitions, and 14% (n = 31) also had training in performance. Twenty five respondents indicated training in other areas; this included journalism, data mining and analysis, statistics, and scientific animation.

We also took the opportunity within the survey to ask about the areas people would like training in (**Figure 2**), with many responses coinciding with aspects of the training already undertaken to a lesser degree by others in the previous question. Visual communication (65%, n = 272), making videos or podcasts (64%, n = 271), storytelling (59%, n = 248), public engagement (56%, n = 234), media training (56%, n = 234) and social media for public engagement or outreach (53%, n = 224) were indicated to be of interest by over half of the respondents to this question. The remaining categories all proved popular amongst some respondents, though training in performance was the least popular option (30%, n = 124) which may be reflective of the high number of respondents working in areas such as journalism, public relations and blogging who may not require skills to directly interact with the public.

We also provided the opportunity for respondents to suggest areas of training they would like to receive, which had not been listed or discussed in the survey. Responses to this question included training in web design, statistics, publishing including the production of magazines and books, teaching, working with young people, financial aspects of project management including fundraising, as well as public-centered design and how to involve people in research not just communicate to them.

One respondent also suggested that training in how and for whom science communicators should evaluate their work was important: "Assuming that we do it seriously and not as a hobby once a year, it becomes an important barrier or springboard for action". In a further question on the survey we asked respondents specifically about their experience in evaluation. Almost three quarters (70%, n = 313) of respondents said that they personally, or others they worked with, gathered evaluation data. Of the 25% (n = 114) of respondents who said they did not gather evaluation data, 8% (n = 38) said they did not have evaluation skills. The remaining respondents either reported that they did not have the time to undertake evaluation (10%, n = 47), or that it was not relevant to their work (6%, n = 29) suggesting this is not an issue of training alone.

Competences Taught in Science Communication Programs

Turning to the question of how science communication programs equip science communicators with required competences, we now take a closer look at those programs across Europe. Due to the exploratory nature of our study, we cannot say much about differences in training and also have refrained from indicating national differences. Rather, our attempt is to give a general impression of how programs address competences required for contemporary science communication.

The sample of respondents consists of 13 participants; their position in the organization can either be described as program managers (n = 11) or lecturers (n = 7) or as a combination of these occupations. Men and women were roughly equally represented (46 and 54%). Concerning different age groups, most individuals were between the age of 40–59 (n = 9). Their highest academic qualifications were Master (n = 2), Doctorate (n = 10) or other postgraduate degrees (n = 1). Regarding experience in science communication, they stated work experience of 5–10 years (n = 4), 11–15 years (n = 2), 16–20 years (n = 2) or over 20 years (n = 4) in the field. With respect to how long they had been teaching science communication, there were slight differences. 5–10 years was stated by 5 individuals, 11–15 years by 2 individuals, 16–20 years by 2 individuals and over 21 years by one respondent. Furthermore, the respondents showed a diversity of disciplinary backgrounds from which they draw their experience, including sociology or Science and Technology Studies (n = 4), communication science and media studies (n = 7) or physical and life sciences (n = 7).

The 13 programs that were involved in our exploratory study were introduced between 2000 and 2010 (N = 4) or between 2011 and 2019 (N = 7). One course had been running since 1993, whilst for one course it was not clear when the program was introduced (one respondent provided a "don't know" answer to that question). Most of the programs were evaluated and revised on a regular basis. We also asked for the number of graduates of these science communication programs; these ranged from 10 to 25 students per year, with most of the programs running with approximately 20 students. Most graduates work in communication related fields, specifically in strategic communication, journalism and media production and presenting. Other common employment amongst graduates included teaching/tutoring, administration, management, research, museums and science centers or scientific publishing. We asked surveyed program managers for the content of curricula of their science communication programs, especially with regard to the competences taught and the ways in which programs address the changes seen in science communication due to the digital transformation.

We first investigated to what extent different kinds of competences and knowledge are taught in programs by asking about learning goals. Results show that both science communication knowledge, such as knowing the public sphere and the media system, and competences to build a trustful relationship with audiences are seen as highly relevant for graduates in the field. Affective goals, for example to experience excitement about one's profession, are also desirable outcomes as is the capacity to think outside the box. Moreover, results show that all of the master programs deal at least to some extent with the digital transformation and related implications for science communicators (**Figure 3**). However, their perspectives differ as to how much attention this is given. One third of program managers emphasize that the digital transformation of science communication is such an important and pervasive topic that it is part of the entire curriculum and integrated into every module, whereas other program managers explain that digital media are only taught in parts of the program.

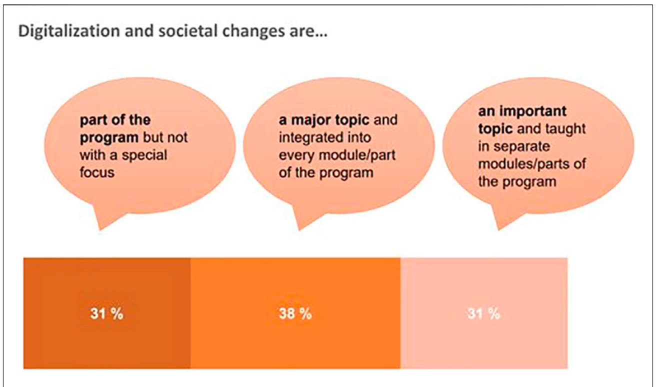

FIGURE 3 | Relevance of digitalization and related changes in the surveyed programs, in %; N = 13.

Overall, participants answered that their programs were either practical skills oriented (6 mentions) or equally theoretical and skills oriented (7 mentions) which indicates that working knowledge is regarded as the most important level of competences taught in most cases.

However, our research shows that most of the programs still address different levels of competences, which are required to perform as a professional communicator in the complex and digitalized science communication landscape. Most program managers indicate that curricula are developed to educate students for communicator roles that foster interaction between science and the public, rather than serving as traditional gatekeepers (**Figure 4**). The "mediator role" is considered especially important to serve the need for interactive communication in digital contexts. However, traditional journalistic role perceptions like agenda setting or gatekeeping/-watching, with science communicators primarily "watching" and editing external information for audiences, still remain important for some program managers. These traditional science communication roles indicate that the conception of science communication as expressed in the deficit model is still prevalent in some programs.

An important part of science communication practice is to recognize the risks and opportunities of public communication. Against this backdrop, we asked how programs address the development of competences. Our results indicate that programs anticipate the features of digital communication, thus referring to interactivity, diversity of communicators and audiences. Also, programs highlight opportunities afforded by digital media like diversity of content or positive impacts on public engagement, as is the need to be aware of critical aspects like the strategic misuse of communication. According to surveyed program managers, students are encouraged to develop critical thinking, and are trained to be able to evaluate scientific information and its reliability, as well as to assess the

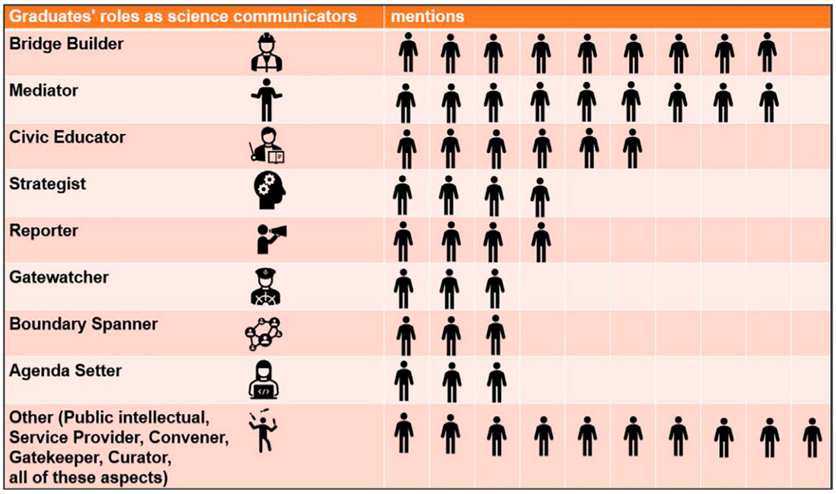

FIGURE 4 | Graduate roles as science communicators up to five mentions.

reliability of different types of sources. Furthermore, we were interested in capturing specific elements of digital media, such as whether programs address opportunities to reach diverse audiences and interactivity. The research suggests that most programs consider the availability of different multimedia content, the need for diversity of communicators and perspectives, as well as the diversity of audiences on digital platforms. Other dimensions of the internet environment, for example currency of information and interaction possibilities, received moderate support which means that these issues are included to a lesser extent in programs.

DISCUSSION

Previous research into science communication training is fragmented, with much literature focused on the training experience and needs of scientists. Little work has explored the training experiences of a broader range of science communicators, with little known about the ways in which "new" communicators, such as social media influencers, corporate communicators or activists acquire their skills and knowledge. Similarly, there is no standard curriculum for science communication postgraduate programs (e.g. Davies and Horst, 2016; Bankston and McDowell, 2018), though propositions for curricula exist (e.g. Longnecker and Gondwe, 2014). Our research has sought to fill this gap by exploring the ways in which a broad range of science communicators acquire competence in science communication and their perceptions of training needs. This has been combined with an explorative survey of European postgraduate science communication programs. In framing this discussion we return to the approaches articulated by Baram-Tsabari und Lewenstein (2017) and Pieczka (2002), seeking to enunciate a framework in which competences could be understood.

Pieczka (2002) outlines three mutually enforcing layers of competence, which we have reformulated for science communication drawing on the work of prior scholars and exploring the ways in which these competences are illustrated through our data. These are organized as "working knowledge", "professional norms and roles", and "picture of the world". **Table 2** gives an overview of competence levels and how they can be addressed in science communication training.

"Working knowledge": this refers to the communication skills (e.g., writing for non-expert audiences) and knowledge of communication tools (e.g., specific digital platforms). Responses to our survey of practitioners suggests that, like scientists (e.g., see Besley et al., 2016; Altman et al., 2020), practitioners tend to focus on acquisition of specific skills in communication, though these may be different skills than those sought by scientists. Altman et al. (2020), for example, identifies scientists as seeking skills around the use of plain language or face-to-face communication, while survey respondents focused on areas such as training in visual communication, making videos and podcasts or storytelling. Open responses to the survey also tend to focus on core "doing" skills, rather than conceptual knowledge (picture of the world) or professional roles. A similar picture is seen in the focus of science communication postgraduate programs, with nearly half indicating their program as primarily skills oriented.

Baram-Tsabari and Lewenstein (2017) highlight that this working knowledge must keep up with new developments, which would include developments in digital technologies. Within this context it is notable that practitioners tended to focus on specific skill sets rather than the tools or conceptual knowledge that would be needed to critically engage with the rapid transformations taking place. All of the postgraduate programs surveyed focused on digital skills, though the extent to which these were integrated or feature as distinct modules varied. Nevertheless, program managers were concerned about developing skills relevant to digital contexts, such as

TABLE 2 | Competence layers as basis for science communication training (adopted categories from Pieczka, 2002).

Competence level	Refers to	Develops through
Picture of the world	–Overall “mental models” –Perceptions of the changing societal framework in which science communication takes place and how it affects the conditions for the interactions of science and society	–Offering new insights and perspectives –(Guided) observation and reflection –Challenging existing mind sets and world views
Professional norms and roles	–What it means to be “professional” –Guiding norms, values, demands and role models developed by science communication as a field of practice –Self-perceptions and others’ perceptions of roles	–Getting to know and adapting professional standards –Interaction, (self)reflection, feedback, developing and adjusting of professional attitudes
Working Knowledge	–Skills and practical knowledge –Capability to deal with technical, strategic and operational demands of every day science communication practice	–Getting to know models, methods and techniques –Practical training, e.g. use of examples and application to other cases –Analyzing problems and failures and searching for ways of improvement

understanding of interactivity, as well as the nature of digital audiences.

“Professional norms and roles”: Following Pieczka (2002) idea of the “conceptual frame” and other authors, competences in this area can refer to specific attitudes that distinguish professional communicators from others. For instance, applying integrated communication on different channels (Longnecker, 2016), considering ethical standards (Besley et al., 2015) and being aware of the importance of evaluating science communication (Jensen, 2014), might be considered professional norms. In this context, it is encouraging that the majority of practitioners responding to the survey undertake evaluation of their activities. Practitioners responding to the survey highlight a number of informal ways in which they acquire science communication expertise, including through watching and learning from others, informal mentoring and degree programs, all of which might be expected to play a role in learning and developing an understanding of professional norms and roles. Nevertheless, relatively few have undertaken formal qualifications in journalism, media or science communication. Within this context, based on our surveys, we argue that being aware of one’s own and others’ roles and related demands (e.g., knowledge broker, curator, bridge builder, enabler) and how to fill these roles may also be considered as important competences, competences which might be acquired through observation and mentoring within training. Our results also suggest science communicators develop these competences formally, within taught programs through learning approaches that foster interaction and self-reflection and allow for feedback, development and adjustment of professional norms and roles.

Yuan et al. (2017) suggest that scientists have limited understanding or interest in two-way methods of science communication, and as a result that few are likely to achieve real dialogue with their publics. There was considerable variation amongst our survey respondents as to whether they had received training in public engagement or communication, and we recognize that definitions of these approaches can vary, but it is encouraging that over half of respondents identified this as an area in which they would like training. Furthermore, program leaders indicate that graduates tend to take on roles that foster interaction, such as bridge builder or mediator, rather than more traditional “translator” roles such as gatekeeper, suggesting that formal education has a role to play in fostering and developing professional norms in the field. A further aspect of professional norms which has been identified particularly in a digital context is a concern with the ethics of communication (Besley et al., 2015). Although not directly raised by survey respondents or program managers in this research, this is an important facet of competence in the area of professional norms and roles.

Turning to “Picture of the world”: science communication is currently contending with societal changes due to globalization and digitalization and these are creating associated demands for professional (science) communicators. Emerging formats for science communication are characterized by activity and pace and their ability to allow citizens to take part in an environment with “new orders of knowledge” (Neuberger et al., 2019). These provide positive effects like new fora for deliberation and more flexible modes of communication but there are also risks that science communicators should be aware of, for example the misuse of science related information. The COVID-19 pandemic has demonstrated not only the vital role of science communication in public health and combating misinformation, but also how social inequalities, in who has both access to and how communities are served with information, remain during such times of crisis (Judd and McKinnon, 2021).

We observe that many of the practitioners responding to our survey had backgrounds in the natural sciences. At this stage it is unclear to what extent this background shapes their picture of the world, but it seems likely that many practitioners engaging in science communication will be science enthusiasts. Equality, diversity and inclusion have previously been identified as issues that need to be addressed in science communication (Dawson, 2019) and which are often missing from training programs (Heslop et al., 2021). Responses from program managers suggest that a focus on inclusion and diversity (both of communicators and audiences) is a focus for education, though based on our survey responses, practitioners may not pro-actively demand training in this area.

For science communication programs and trainers to develop science communicators’ picture of the world means to develop the mental models of students and the ways in which they perceive the changing societal framework in which science communication takes place and how it affects the conditions for the interaction of science and society. Competences that refer to the picture of the world can be developed by offering students new insights, by taking on new perspectives, by supporting them to make their own observations and reflect those and by challenging mindsets and world views in the context of interactional approaches. Digitalization may offer opportunities for a wider range of communicators to contribute to the science–society discourse, though it remains unknown whether this will be a more inclusive space. There remain important questions around misinformation in social and digital media and how this is regulated, but in the meantime we may require science communication training not only to be more agile but also open, reflexive and responsive (Roedema et al., 2021). Further, new tools may offer ways to include more diverse audiences in the conversation; whether this promise can be enacted needs further analysis.

Our results are limited, due to the exploratory nature of our study and the focus on a small number of European countries. Though we extended our survey of science communicators to a broader range of science communicators than some past work on the context of training, and we were also able to access programs throughout Europe, we also recognize limitations in the self-reported nature of our results. Therefore future studies on a more representative European sample, as well as a wider range of cultural settings, would be beneficial. The survey of science communicators' data also formed part of a much wider questionnaire encompassing the motivations, working practices and constraints communicators work under, affording limited opportunity to ask specific questions relating to Piezcka's three levels of expertise. So while this aspect of the analysis should be treated as exploratory, it still provides useful insights.

The creation of one centralized online resource with course information could also be a useful starting point to further consider programs against this model (Bankston and McDowell, 2018). Those training resources could be tested in future studies to evaluate whether these would improve learning outcomes.

Our research provides a starting point for the development of a competence framework that draws on the experiences of science communication professionals and the curricula offered through science communication degree programs. In this context, we have specifically focused on the ways that science communication training can contribute to equip prospective science communicators with competences needed to cope with the demands posed by the complex digital media landscape. These results point to the usefulness of comparing programs and training in different countries, albeit all European, in order to ascertain understanding and knowledge of science communication training, as well as the value of researching the views of both trainers and science communicators themselves.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by UWE Bristol and Zeppelin University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BF, CW, EW, LH, AR and EM contributed to conception and design of the study and analysis of data. BF, CW, and EW wrote the first draft of the manuscript. LH and EM designed figures and contributed to the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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REFERENCES

Akin, H., Rodgers, S., and Schultz, J. (2021). Science Communication Training as Information Seeking and Processing: a Theoretical Approach to Training Early-Career Scientists. *JCOM* 20 (05), A06. doi:10.22323/2.20050206

Altman, K., Yelton, B., Hart, Z., Carson, M., SchanderaKelsey, L. H., Kelsey, R. H., et al. (2020). "You Gotta Choose Your Words Carefully": Findings from Interviews with Environmental Health Scientists about Their Research Translation Perceptions and Training Needs. *J. Health Commun.* 25 (5), 454–462. doi:10.1080/10810730.2020.1785060

Bankston, A., and McDowell, G. S. (2018). Changing the Culture of Science Communication Training for Junior Scientists. *J. Microbiol. Biol. Educ.* 19 (1), 1–6. doi:10.1128/jmbe.v19i1.1413

Baram-Tsabari, A., and Lewenstein, B. V. (2017). Science Communication Training: what Are We Trying to Teach? *Int. J. Sci. Educ. B.* 7 (3), 285–300. doi:10.1080/21548455.2017.1303756

Bartle, E., Longnecker, N., and Pegrum, M. (2011). Collaboration, Contextualisation and Communication Using New Media: Introducing Podcasting into an Undergraduate Chemistry Class. *Int. J. Innovation Sci. Math. Educ.* 19 (1), 16–28.

Besley, J. C., Dudo, A., and Storksdieck, M. (2015). Scientists' Views About Communication Training. *J. Res. Sci. Teach.* 52 (2), 199–220. doi:10.1002/tea.21186

Besley, J. C., Dudo, A. D., Yuan, S., and Abi Ghannam, N. (2016). Qualitative Interviews with Science Communication Trainers about Communication Objectives and Goals. *Sci. Commun.* 38 (3), 356–381. doi:10.1177/1075547016645640

Collins, K., Shiffman, D., and Rock, J. (2016). How Are Scientists Using Social Media in the Workplace? *PLoS ONE* 11 (10), e0162680. doi:10.1371/journal.pone.0162680

Copple, J., Bennett, N., Dudo, A., Moon, W.-K., Newman, T. P., Besley, J., et al. (2020). Contribution of Training to Scientists' Public Engagement Intentions: A Test of Indirect Relationships Using Parallel Multiple Mediation. *Sci. Commun.* 42 (4), 508–537. doi:10.1177/1075547020943594

Davies, S. R., Franks, S., Roche, J., Schmidt, A. L., Wells, R., and Zollo, F. (2021). The Landscape of European Science Communication. *JCOM* 20 (03), A01. doi:10.22323/2.20030201

Davies, S. R., and Horst, M. (2016). *Science Communication: Culture, Identity and Citizenship*. London: Palgrave Macmillan.

Dawson, E. (2019). *Equity, Exclusion and Everyday Science Learning: The Experiences of Minoritised Groups*. Abingdon, Oxon: Routledge.

Dudo, A., Besley, J. C., and Yuan, S. (2021). Science Communication Training in North America: Preparing Whom to Do what with what Effect? *Sci. Commun.* 43 (1), 33–63. doi:10.1177/1075547020960138

Faehnrich, B. (2021). Conceptualizing Science Communication in Flux - a Framework for Analyzing Science Communication in a Digital media Environment. *JCOM* 20 (3), Y02. doi:10.22323/2.20030402

Fähnrich, B. (2020). Deliverable 3.2 Report on Experts' Views on Current Science Communication Quality and Demands. Available at: https://zenodo.org/record/4061349#.YMM9881KjIV (Accessed June 11th, 2021).

Fahy, D., and Nisbet, M. C. (2011). The Science Journalist Online: Shifting Roles and Emerging Practices. *Journalism* 12 (7), 778–793. doi:10.1177/1464884911412697

Gascoigne, T., Schiele, B., Leach, J., Riedlinger, M., Lewenstein, B. V., Massarani, L., et al. (2020). *Communicating Science - A Global Perspective*. Canberra: ANU Press. doi:10.22459/CS.2020

Heslop, C., Dudo, A., and Besley, J. C. (2021). *Overview of the UK Science Engagement Training Community*. Austin: Centre for Media Engagement.

Howell, E. L., and Brossard, D. (2020). "Science Engagement and Social media: Communicating across Interests, Goals, and Platforms," in *Routledge Studies in Environmental Communication and media. Theory and Best Practices in Science Communication Training*. Editor T. P. Newman (Abingdon, Oxon: Routledge).

Illingworth, S., and Roop, H. (2015). Developing Key Skills as a Science Communicator: Case Studies of Two Scientist-Led Outreach Programmes. *Geosciences* 5 (1), 2–14. doi:10.3390/geosciences5010002

Ishihara-Shineha, S. (2021). Policy Inconsistency between Science and Technology Promotion and Graduate Education Regarding Developing Researchers with Science Communication Skills in Japan. *East Asian Sci. Tech. Soc. Int. J.* 15 (1), 46–67. doi:10.1080/18752160.2020.1857051

Jensen, E. (2014). The Problems with Science Communication Evaluation. *JCOM* 13, 01C04. doi:10.22323/2.13010304

Judd, K., and McKinnon, M. (2021). A Systematic Map of Inclusion, Equity and Diversity in Science Communication Research: Do We Practice what We Preach? *Front. Commun.* 6, 208. doi:10.3389/fcomm.2021.744365

Kahan, D. M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L. L., Braman, D., et al. (2012). The Polarizing Impact of Science Literacy and Numeracy on Perceived Climate Change Risks. *Nat. Clim Change* 2 (10), 732–735. doi:10.1038/nclimate1547

Longnecker, N. (2016). An Integrated Model of Science Communication - More Than Providing Evidence. *JCOM* 15 (05), Y01. doi:10.22323/2.15050401

Longnecker, N., and Gondwe, M. (2014). "Graduate Degree Programmes in Science Communication: Educating and Training Science Communicators to Work with Communities," in *Communicating Science to the Public*. Editors L. Tan Wee Hin and R. Subramaniam (Dordrecht: Springer), 141–160. doi:10.1007/978-94-017-9097-0_9

Longnecker, N. (Forthcoming 2021). "Good Science Communication Considers the Audience," in *Science + SciComm + Work: Effective Communication in Science Programs. A Practical Guide for Students and Teachers*. Editors S. Rowland and L. Kuchel (Basingstoke: Springer).

Milani, E., Ridgway, A., Wilkinson, C., and Weitkamp, E. (2021). Reaching Underserved Audiences: How Science Communicators Are Making New Connections Using Innovative Techniques. Deliverable 1.4. Available at: https://www.rethinkscicomm.eu/wp-content/uploads/2021/04/RETHINK_Derivable_D1.4_V11_FINAL-1.pdf (Accessed August 2nd, 2021).

Milani, E., Ridgway, A., Wilkinson, C., and Weitkamp, E. (2020). Report on the Working Practices, Motivations and Challenges of Those Engaged in Science Communication. Deliverable 1.2. Available at: https://www.rethinkscicomm.eu/wp-content/uploads/2020/06/RETHINK_-D1.2-Report-on-the-working-practices-and-motivations-and-challenges-of-those-engaged-in-science-communication.pdf (Accessed March 15th, 2021).

Milani, E., Ridgway, A., Wilkinson, C., and Weitkamp, E. (2019). Scoping Report on the Science Communication Ecosystem. Deliverable 1.1. Available at: https://www.rethinkscicomm.eu/wp-content/uploads/2020/06/D1.1-Scoping-Report-on-the-Science-Communication-Ecosystem.pdf (Accessed March 15th, 2021).

Miller, S., and Fahy, D.The ESConet Team (2009). Can Science Communication Workshops Train Scientists for Reflexive Public Engagement? *Sci. Commun.* 31 (1), 116–126. doi:10.1177/1075547009339048

Mulder, H. A. J., Longnecker, N., and Davis, L. S. (2008). The State of Science Communication Programs at Universities Around the World. *Sci. Commun.* 30 (2), 277–287. doi:10.1177/1075547008324878

Neuberger, C., Nuernbergk, C., and Langenohl, S. (2019). Journalism as Multichannel Communication. *Journal. Stud.* 20 (9), 1260–1280.

Pieczka, M. (2002). Public Relations Expertise Deconstructed. *Media, Cult. Soc.* 24 (3), 301–323. doi:10.1177/016344370202400302

Pielke, Jr, R. A. (2007). *The Honest Broker: Making Sense of Science in Policy and Politics*. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511818110

Rifkin, W, N., Longnecker, N., Leach, J., Davis, L. S., and Orthia, L. (2010). Students Publishing in New media: Eight Hypotheses – a House of Cards? *Int. J. Innovation Sci. Math. Educ.* 18 (1), 43–54.

Rodgers, S., Wang, Z., Maras, M. A., Burgoyne, S., Balakrishnan, B., Stemmle, J., et al. (2018). Decoding Science: Development and Evaluation of a Science Communication Training Program Using a Triangulated Framework. *Sci. Commun.* 40 (1), 3–32. doi:10.1177/1075547017747285

Rodgers, S., Wang, Z., and Schultz, J. C. (2020). A Scale to Measure Science Communication Training Effectiveness. *Sci. Commun.* 42 (1), 90–111. doi:10.1177/1075547020903057

Roedema, T., Streekstra, K., Berendrecht, E., de Vries, Y., Ramaaker, E., Schoute, K., et al. (2021). Deliverable 2.4 Strategies towards a Reflective Practice for Science Communicators. Available at: https://www.rethinkscicomm.eu/wp-content/uploads/2021/07/RETHINK_D2.4_Report-on-the-effectiveness-of-engagement-strategies-to-enhance-openness-and-reflexivity-3.pdf (Accessed November 15th, 2021).

Royal Society (2006). *Science Communication: Survey of Factors Affecting Science Communication by Scientists and Engineers*. London: Royal Society.

Rubega, M. A., Burgio, K. R., MacDonald, A. A. M., Oeldorf-Hirsch, A., Capers, R. S., and Wyss, R. (2020). Assessment by Audiences Shows Little Effect of Science Communication Training. *Sci. Commun.* 43 (2), 139–169. doi:10.1177/1075547020971639

Silva, J., and Bultitude, K. (2009). Best Practice in Communications Training for Public Engagement with Science, Technology, Engineering and Mathematics. *JCOM* 08 (02), A03. doi:10.22323/2.08020203

Stylinski, C., Storksdieck, M., Canzoneri, N., Klein, E., and Johnson, A. (2018). Impacts of a Comprehensive Public Engagement Training and Support Program on Scientists' Outreach Attitudes and Practices. *Int. J. Sci. Educ. Part B.* 8 (4), 340–354. doi:10.1080/21548455.2018.1506188

TNS-BRMB (2015). *Factors Affecting Public Engagement by Researchers: A Study on Behalf of a Consortium of UK Public Research Funders*. London: TNS-BRMB and Policy Studies Institute.

Turney, J. (1994). Teaching Science Communication: Courses, Curricula, Theory and Practice. *Public Underst Sci.* 3 (4), 435–443. doi:10.1088/0963-6625/3/4/006

Walker, G., Bantsi, L. B., Bukhosini, S., Chikundi, K., Dusrath, A., Kafeero, M., et al. (2020). Models to Build Capacity for African Science Centres and Science Communication: Needs and Assets. *JCOM* 19 (01), A05. doi:10.22323/2.19010205

Weber, C., Allen, S., and Nadkarni, N. (2021). Scaling Training to Support Scientists to Engage with the Public in Non-traditional Venues. *JCOM* 20 (4), N02. doi:10.22323/2.20040802

Weitkamp, E., Milani, E., Ridgway, A., and Wilkinson, C. (2021). Exploring the Digital media Ecology: Insights from a Study of Healthy Diets and Climate Change Communication on Digital and Social media. *JCOM* 20 (3), A02. doi:10.22323/2.20030202

Yuan, S., Oshita, T., AbiGhannam, N., Dudo, A., Besley, J. C., and Koh, H. E. (2017). Two-way Communication between Scientists and the Public: a View from Science Communication Trainers in North America. *Int. J. Sci. Educ. Part B* 7 (4), 341–355. doi:10.1080/21548455.2017.1350789

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