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Top Indian scientists as public communicators: a survey of their perceptions, attitudes and communication behaviors

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Abstract
Research on science communication, especially from scientists' point of view, is rare in the Indian context. This first of its kind study in India explores the perceptions and attitudes toward science communication of senior and experienced Indian scientists ($N=259$). Based on a cross-sectional survey of scientists who are elected fellows of three Indian national science academies, it provides a snapshot of what Indian scientists think about their involvement, performance, and experience in public engagement activities and the perceived impact of their involvement in such activities. It also provides a diagnosis about the use of different ways of public communication by Indian scientists. The results show that almost all the respondents have participated in some science communication activity during their careers, and the majority of their affiliated institutions organized such activities. A vast majority of the respondents had a positive experience in public engagement and expressed willingness to engage in the future as well. More than three-quarters of the respondents personally enjoyed taking part in science communication while feeling that they were confident and well-equipped to communicate their research. The results from this survey are discussed with possible implications for future policies on science communication by scientists and devising appropriate inventions for enhancing their engagement.

Keywords Science communication · Public engagement · Science outreach · Indian scientists · Science communication policy

Introduction

Despite favorable constitutional and policy provisions for promoting scientific awareness and engagement, the field of science communication, both professionally and academically, is marred with several hindrances in India. Such hindrances include the challenges faced by scientists in actively engaging with the public or contributing to science communication efforts, lack of institutional priority for science communication, institutional policies restricting journalists' access to scientists, lack of opportunities in professional training

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and academic research in science communication, large socio-cultural and linguistic diversity, illiteracy and poverty limiting access to scientific content, non-availability of popular science material in regional languages, and poor media coverage of science. However, soon after independence, the Indian government was quick to recognize the importance of spreading scientific awareness among the public as a priority area in India's first science policy document (Scientific Policy Resolution, 1958). This importance was consistently emphasized by the subsequent science policies (Technology Policy Statement 1983, Science and Technology Policy 2003, and Science Technology and Innovation Policy 2013). Also, the Constitution of India requires every citizen to 'develop the scientific temper, humanism and the spirit of enquiry and reform' as a fundamental duty (Part-IV, Article 51A(h), 42nd constitutional amendment of the Constitution of India, 18 December 1976).

Further, the Government of India's two new draft policies—the Scientific Social Responsibility (SSR) Policy 2019, and the Science, Technology and Innovation (STI) Policy 2020—lay even more emphasis on promoting science communication and public engagement in the country. The SSR Policy mandates ten working days of public engagement as a social responsibility of every scientist while also suggesting several interventions for enhancing engagement between science and society (Department of S&T, 2019). The draft STI Policy 2020 goes one step ahead and proposes establishing science communication wings at every public-funded R&D institution (Department of S&T, 2020). If implemented, this proposal would address the longstanding demand for science communication specialists or units at R&D organizations to promote and institutionalize science popularization (Salwi, 2002). The proposed STI policy emphasizes training and capacity building in science communication skills through short- and long-term courses and workshops, integrating science communication at different levels of science education from school to university, and promoting interdisciplinary research in science communication. If implemented properly, these two new policies are expected to bring a paradigm shift in the science communication landscape in India, both professionally and academically.

But so far, research in science communication in India is still at its infancy stage (Rajput, 2017), especially there is a lack of literature on what sense Indian scientists make of science communication and how they engage. To reap better results from these recent policies encouraging public engagement by scientists, systematic studies providing empirical evidence on what scientists think about their engagement, performance, experience, and willingness to engage in public engagement activities and the possible impact of their engagement would be helpful. Such evidence would help guide policy for enhancing scientists' participation in science communication and public engagement activities. However, no significant studies are known to explore the attitudes and perceptions of Indian scientists about their engagement in science communication activities.

Literature review

The existing literature on science communication globally (in English), in general, has given relatively more emphasis to understanding public perceptions about science than exploring the perceptions and attitudes of scientists about their public engagement (Ecklund et al., 2012). However, with increasing demands for an active role of scientists in disseminating scientific information to the public from different stakeholders, including policymakers, funding agencies, science and science communication leaders, and the general public (e.g., Agre & Leshner, 2010; Burchell, 2015; Dudo & Besley, 2016;

Nisbet & Scheufele, 2009; Royal Society, 1985, 2006; Shugart & Racaniello, 2015; Wellcome Trust, 2001), several studies in other parts of the world (especially in the West and the European countries) have tried to understand scientists' perceptions and attitudes about science communication (e.g. Besley & Nisbet, 2013; Burchell, 2015; Davies, 2008; Ecklund et al., 2012; Guerrero, 2016; Ho et al., 2020; Kreimer et al., 2011; Loroño-Leturiondo & Davies, 2018; Martin-Sempere et al., 2008; Merino & Navarro, 2019; Nielsen et al., 2007; Royal Society, 2006; Valinciute, 2020; Wellcome Trust, 2001). At the same time, such studies are rare in the Asian, or specifically in the Indian, context.

A clear understanding of scientists' perceptions and attitudes about science communication and public engagement would be desirable before entrusting scientists with the task of public engagement either voluntarily or mandatorily through policy. Public engagement with science is not just a mechanical activity but a complex process involving transforming sense or meaning from scientific language to the audience's language (Davies, 2008; Grillo et al., 2016). When it is the transmission of knowledge through the retelling of scientific discourses into the language of the target audience (Grillo et al., 2016), it also requires establishing a two-way active dialogue between science and society (Varner, 2014). To achieve this, scientists are required to play an important role, at least as a link between science and society. Scientists cannot be expected to play this role without understanding and addressing their requirements, impediments, and expectations (e.g., Andrews et al., 2005; Gascoigne & Metcalfe, 1997). An understanding of personal relevance, motivations and factors influencing scientists' public engagement would contribute to making science communication by scientists more effective (Andrews et al., 2005; Kreimer et al., 2011; Poliakoff & Webb, 2007; Varner, 2014). However, such an understanding is lacking in the Indian context.

Scientists generally believe that time constraint is a big hindrance in their way to active involvement in science communication activities (Andrews et al., 2005; Gascoigne & Metcalfe, 1997; Ho et al., 2020; Poliakoff & Webb, 2007). Several studies also suggest that lack of incentives/rewards (Ecklund et al., 2012; Gascoigne & Metcalfe, 1997), lack of institutional support and encouragement (Kreimer et al., 2011; Royal Society, 2006; Valinciute, 2020), labelling as a publicist or the stigma of Sagan effect (Ecklund et al., 2012; Merino & Navarro, 2019; Rose et al., 2020; Royal Society, 2006; Shugart & Racaniello, 2015), deviation from doing research (Royal Society, 2006), lack of funding (Valinciute, 2020), no personal benefit (Valinciute, 2020), no benefits in career advancement (Agnella et al., 2012; Jensen, 2011; Poliakoff & Webb, 2007; Shanley & López, 2009; Watermeyer, 2015), difficulty in crafting messages for the non-scientist audiences (Andrews et al., 2005; Ecklund et al., 2012; Gascoigne & Metcalfe, 1997; Shugart & Racaniello, 2015), and research being too complex for the public to understand (Kreimer et al., 2011; Valinciute, 2020) are the likely factors preventing scientists from active participation in science communication. Lack of training, communication skills and experience also impede scientists' public engagement (Andrews et al., 2005; Ecklund et al., 2012; Shugart & Racaniello, 2015; Yuan et al., 2017). Having no exposure to public communication, many scientists often find it difficult to talk in common terms. Here, scientists' use of scientific jargon becomes a barrier to connecting with the larger society (Bullock et al., 2019; Sharon & Baram-Tsabari, 2014; Shulman et al., 2020; Smith & Merkle, 2021). Misquoting, misreporting or sensationalization by media (Bell, 1994; Ransohoff & Ransohoff, 2001; Rinaldi, 2012; Weigold, 2001) often creates controversies that further deter scientists from talking to journalists and so impacting their involvement in science communication activities. Several of these barriers and impediments make scientists shy away from engaging with the media or the public.

On the other hand, several studies conducted in countries other than India suggest that providing appropriate incentives, rewards, encouragement, recognition, funding, training, policy guidelines, career benefits, and making science communication explicit part of the job, would encourage scientists to engage more with the public (e.g., Andrews et al., 2005; Burchell, 2015; Farahi et al., 2019; Gascoigne & Metcalfe, 1997; Ho et al., 2020; Rose et al., 2020; Royal Society, 2006; Yuan et al., 2017). Interestingly, even in the absence of all these, many scientists in different parts of the world believe that it is their moral duty and responsibility to share their research findings with the taxpayers or the larger public (AAAS, 2015; Conradie, 2004; Farahi et al., 2019; Hamlyn et al., 2015; Llorente et al., 2019; Merino & Navarro, 2019; Royal Society, 2006; Roten, 2011; Searle, 2011; Wellcome Trust, 2001).

With this brief background, we appreciate that science communication by scientists is gaining considerable importance in literature. In the last around two decades, several studies have been conducted in different parts of the world to understand scientists' perceptions, attitudes, and experiences in this regard and the possible incentives, factors and impediments related to their public engagement. However, such studies are rare in the Indian context. India is a complex and diverse society with many languages and ethnicities. Connecting such diverse people with science has always been a challenge. With the lack of trained and skilled science communicators (especially in local languages) who can contextualize scientific knowledge for the local audience, science communication even becomes more difficult. In such contexts, there are demands that Indian scientists should play an active role in communicating science with the public, especially with their own local and linguistic communities. Even when these demands are getting noticed in the new policies (Department of S&T, 2019, 2020), we lack empirical evidence addressing the readiness and willingness of Indian scientists to engage with the public. We do not know much about scientists' attitudes and perceptions about their public engagement performance and experiences, which would better guide policies in this direction. With the field of science communication largely remaining unexplored and ignored in the Indian academia, the current study attempts to address this important gap in the literature in the Indian context.

Over the last 3–4 decades, science communication has gone through different phases of evolution and today, it is being recognized as a specialized area of academic and professional expertise across the globe. Different scholars and practitioners have called it by various names including: public understanding of science, science literacy, public awareness of science, scientific awareness, science popularisation, public communication of science and technology, science outreach, and public engagement. However, the term 'science communication' is increasingly getting wider acceptance for describing the activities of communicating scientific knowledge to non-scientist audiences. Another popular term is 'public engagement.' Davis (2010) says science communication is broadly 'the popularisation of science,' wherein the scientific knowledge buried in the technical language of science is distilled into a form that the general public can readily understand. Brake and Weitkamp (2010) explained 'science communication' as the communication of scientific information to public audiences. Calling it 'public engagement,' Poliakoff and Webb (2007) also tried to define it as 'any scientific communication that engages an audience outside of academia' (p. 244). Therefore, the terms 'science communication' and 'public engagement' are used interchangeably in this text.

The current study

In this first of its kind exploratory study in India, senior and experienced Indian scientists who are elected fellows of three Indian national science academies were surveyed to investigate their views and attitudes on the different aspects of science communication. As part of a larger study, this article focuses on what Indian scientists think about their engagement in science communication activities with the public. It explores the attitudes and perceptions of the respondents toward certain aspects of public communication of science in an effort to provide a diagnosis for how scientists are involved in science outreach and engagement activities. It addresses the following questions from the Indian scientists' point of view:

Research Question 1	Overall, how frequently do scientists engage in science communication activities, and how frequently do their institutions organize such activities?
Research Question 2	How frequently do scientists participate in different science communication activities?
Research Question 3	What do Indian scientists think about their engagement practices, performance, and experience in science communication activities?
Research Question 4	If scientists engage in science communication activities, what is their attitude toward the possible impact of their engagement?
Research Question 5	How likely are Indian scientists to engage in science communication in the future?

We also try to explore if the measured variables have any correlations and their possible association with demographic variables.

Methods

Participants and survey

India has three prestigious, respected, and esteemed national science academies—Indian Academy of Sciences (IASc), Bengaluru; Indian National Science Academy (INSA), New Delhi, and National Academy of Sciences, India (NASI), Prayagraj (erstwhile Allahabad). It is a great honour and recognition for any scientist to get elected as a fellow of these academies. It is worth mentioning here that these academies elect scientists or academicians as their fellows only after they have achieved a certain high level of experience and expertise in their respective research areas and have contributed significantly to the advancement of research in their area. IASc elects typically not more than 35 Fellows each year. INSA elects fellows up to a maximum of 40 annually till the total number of living fellows reaches 1000. NASI elects a varying number of fellows every year, with the maximum number of fellows not exceeding 2000.

The elected fellows of these academies are generally top-rated, experienced, and celebrated experts and senior members of their respective fields of expertise. Also, the fellows of these academies come from diverse socio-cultural and linguistic backgrounds in India, a wide range of scientific fields, and different work environments (government/private

academic or research institutions, NGOs, industry) from across the country. Therefore, the elected fellows of these academies were considered an ideal target population to draw a sample of senior and experienced Indian scientists for the current study.

As per the 2018 yearbooks of these academies, IASc, INSA and NASI had 1077, 931 and 1664 elected fellows, respectively. All the valid and available email IDs of the elected fellows were extracted from these yearbooks. Three academy-wise email databases were prepared. The fellows were invited through email to participate voluntarily in this study by filling out an online questionnaire anonymously. Intending to get as many responses as possible, we attempted a census study of these elected fellows in October 2018. Before proceeding to fill out the questionnaire, prior informed consent of the participants was obtained by ticking a checkbox against the consent form at the beginning of the survey. With the initial invitation followed by three email reminders, 306 responses were submitted, but only 259 complete and valid responses were considered for further analysis. Response rates were calculated academy-wise for total responses (306) as 9% for IASc ($n=97$), 5.7% for INSA ($n=53$) and 9.4% for NASI ($n=156$), with the average response rate for the three academies being 8.03%.

Measures

A systematic review of several studies by Burchell (2015) suggests that personal attributes, positive attitudes, and motivational factors play an important role in public engagement (PE) by scientists. To address the research questions of the current study, constructs of perception, attitude, and communication behavior in science communication by Indian scientists' were used. Here, perception and attitude are closely related, however, in simple terms, perception means how people perceive the stimuli for meaningful interpretations based on their experience, with the condition that whatever is perceived may be totally different from the reality (Pickens, 2005). In the current study, scientists' perceptions largely refer to how they view various aspects of science communication from their own perspective. Attitude refers to a mindset or psychological likelihood to see things with some extent of favour or disfavour, like or dislike, based on an individual's experience and temperament (Jung et al., 2015; Pickens, 2005). With a degree of selectivity, attitudes help people see things/situations either positively or negatively and accordingly influence their behavior. So by exploring scientists' attitudes, we want to understand how positively or negatively they are inclined toward the variables under investigation. In this study, communication behavior is intended to reflect how scientists engage in science communication activities (their frequency and use of different modes of communication). The constructs were measured with survey items/questions (measured on Likert scales) as discussed below. These survey items/questions were specifically designed or modified and adopted from the extant literature (especially Hamlyn et al., 2015; Royal Society, 2006; Searle, 2011; Wellcome Trust, 2001) and experiential evidence.

Perceived overall frequency of public engagement

A single item each was used to measure the overall frequency of participants' engagement and that of their institutions organizing such activities. A 4-point scale (1 = Never, 2 = Rarely, 3 = Occasionally and 4 = Often) was used. The respondents were asked to indicate how frequently it was that "you actively engage in science communication activities" and "your institution organizes public engagement activities."

Frequency of scientists' participation in different science communication activities

Today, different (traditional, print, electronic and digital) ways of public communication are available that scientists can potentially use in their public engagements or science communication activities. We wanted to understand which communication ways or activities are used by scientists and how frequently. A manageable list of select six broad communication activities was prepared, making it convenient and simple for the respondents to register their responses. The list includes: (1) Face-to-face interactions with the public (open days/public talks/expos), (2) Talking at schools and colleges, (3) Giving interviews to journalists/reporters, (4) Writing popular science articles/books, (5) Writing about science online (websites, blogs, social media), and (6) Sharing research videos online. The frequency of these six items was measured by asking the respondents "how often you participated in different science communication activities during the last one year" on a 4-point scale (1 = Never, 2 = Once, 3 = 2–5 times, 4 = 6 + times).

Perceptions about engagement, performance and experience

When scientists are asked to engage in science communication activities, it is desirable to understand their views on their capabilities, involvement and performance. We tried to seek respondents' views on the following variables that can be potential predictors for scientists' public engagement or can affect their communication behaviors.

Ease/difficulty of public engagement A single item was used to measure the respondents' perceived ease/difficulty of engagement by asking them to rate how easy/difficult they find it to engage in science communication activities in general on a 5-point scale (1 = Very Difficult, 2 = Fairly Difficult, 3 = Neutral, 4 = Fairly Easy, 5 = Very Easy).

Overall experience Respondents' overall experience in public engagement was evaluated by asking them, "If you were engaged in any science communication activities in the past, then how your overall experience was so far?" They were asked to rate their experience on a 6-point scale (1 = Very Bad, 2 = Bad, 3 = Average, 4 = Good, 5 = Very Good, 6 = No Opinion).

Rating respondents' own public engagement To assess how the respondents evaluated their own engagement, they were asked "How would you rate your own engagement in science communication with the general public/media?" on a 6-point scale (1 = Very Poor, 2 = Poor, 3 = Average, 4 = Good, 5 = Very Good, 6 = No Opinion).

Personal variables for science communication performance Experiential evidence (based on interactions with many scientists) suggests that scientists are more likely to participate in science communication activities and perform well in their engagement initiatives if they personally enjoy participating in such activities, feel confident about their ability to communicate, and believe they are personally well-equipped to communicate research. Some studies (e.g., Ho et al., 2020; Poliakoff & Webb, 2007; Royal Society, 2006) have also investigated such subjective variables, which can potentially affect scientists' successful performance in public engagement or can be predictors of their likelihood to engage in the future. Accordingly, three statements were developed (1. I personally enjoy taking part in

science communication activities. 2. I am confident about my ability to communicate science. 3. I am personally well equipped to communicate my research.), and the respondents were asked how they agreed with these statements on a 5-point scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree).

Attitudes toward the likely impact of scientists' public engagement

It is understood that whatever we do would have an effect on something. If scientists' participation in science communication has positive outcomes in their professional life, we believe more scientists would be willing to contribute. Based on extant literature and experiential evidence, we prepared a list of six select possibilities that would be impacted by scientists' public engagement. The selected six possibilities are: (1) It will increase the scientific knowledge of the public, (2) It will increase my own scientific knowledge, (3) It will increase my confidence in public communication, (4) It will provide scientific information for wider public use, (5) It will popularise my research, and (6) It will increase public support for my research. To explore the attitudes of scientists toward the possible impact of their public engagement, the respondents were asked to estimate how likely the given six possibilities would happen on a 5-point scale of likelihood (1 = Very Unlikely, 2 = Quite Unlikely, 3 = Neutral, 4 = Quite Likely, 5 = Very Likely) if they engaged in PE activities.

Likelihood to engage in the future

A single item was used to measure the respondents' likelihood to engage in the future by asking them, "Given an opportunity to communicate your research to the public in the future, how likely would you get involved in science communication activities?" on a 5-point scale (1 = Very Unlikely, 2 = Quite Unlikely, 3 = Neutral, 4 = Quite Likely, 5 = Very Likely).

Analysis

For this exploratory study, we mostly relied on frequency data and descriptive statistics. To look for any differences or associations between scientists' public engagement behaviors and demographic variables, we additionally used Chi-square tests for independence and Spearman's correlation coefficient. We used MS Excel and JASP software for statistical analysis of the survey data. Statistical significance was determined by p-value of < 0.05.

Results

Demographics

Most of the respondents identified themselves as male (87.26%), with 84.25% of them saying that they were aged more than 55 years, 81.08% had more than 30 years' experience, 50.96% held senior scientific/administrative positions, 67.96% were affiliated with central R&D institutions and central universities, and 61.78% had more than 100 peer-reviewed publications. For those who are not familiar with the Indian R&D system, central R&D institutions/universities are the ones owned or funded by the Indian (central) government, while the state R&D institutions/universities are the ones owned or funded by the

governments of the Indian states. The respondents belonged to different research/academic disciplines: Biological Sciences (35.14%), Chemical Sciences (7.34%), Computer and IT (3.86%), Earth and Planetary Sciences (6.95%), Engineering and Technology (9.27%), Humanities and Social Sciences (1.16%), Mathematical Sciences (10.04%), Medical Sciences (7.72%) and Physical Sciences (18.53%). Many of the respondents expressed that they were fellows of more than one academy. Please see Table 1 for more on demographic details of the respondents.

Public engagement by individual scientists and their institutions

In general, the survey results suggest that most respondents participated occasionally (49%) in public engagement activities, with about 39.38% participated often, 10.81% rarely and 0.77% never. Similarly, most of the respondents believed that their affiliated institutions organized public engagement activities occasionally (47.49%), with 36.29% organized often, 13.90% rarely and 2.32% never (Table 2).

Based on a series of paired Chi-square tests for independence, the frequency of PE by scientists or their institutions was found to be largely independent of the demographic variables, except for small or moderate differences in a few cases (only the statistically significant cases are shown in Table 2). Individual scientists' frequency of PE activities was found to show insignificant differences with age, gender, affiliation, primary position, experience, and area of research. However, it showed statistically significant differences with the number of publications, χ^2 (15, $N=259$) = 29.042, $p<.05$, but with a small effect size (Cramer's V = 0.193). Here, a specific difference noted is that most respondents with 60–80 peer-reviewed publications (58.06%) and 80–100 publications (53.13%) were more inclined to engage 'occasionally.'

Similarly, Chi-square tests showed no significant differences between public engagement frequency by institutions and demographic variables, except for type of affiliated organisation (χ^2 (21, $N=259$) = 34.301, $p<.05$; moderate effect size with Cramer's V = 0.210) and area of research (χ^2 (24, $N=259$) = 43.986, $p<.01$; moderate effect size with Cramer's V = 0.238). It is noted that most respondents affiliated with central R&D institutions, central universities, private universities, and 'other' believed that their institutions organized PE activities 'occasionally,' while the highest proportion of respondents from NGOs believed that their institutions organized such activities 'often.' Respondents from state R&D institutions and state universities believed their institutions equally participated 'occasionally' and 'often' (50% and 34% each respectively), while private companies organized such activities 'rarely' and 'occasionally' equally (50%). Differences based on the area of research suggest that most respondents from biological sciences, chemical sciences, earth and planetary sciences, mathematical sciences, engineering and technology, medical sciences, and computer and IT believed that their affiliated organizations engaged 'occasionally' in PE activities, while most from physical sciences suggested that their institutions engaged 'often.'

Scientists' participation in different science communication activities

An attempt is made to assess how frequently the respondents participated in science communication activities through different modes of engagement during the last year. As shown in Table 3, the highest percentage of scientists engaged 2–5 times in face-to-face interactions with the public (40.54%) and talking at schools and colleges (41.70%), never

Table 1 Demographic characteristics of the survey respondents ($N=259$)

Demographic variables		Frequency	Percentage
Gender	Male	226	87.26
	Female	33	12.74
Age group	<25 years	0	0.00
	25–35 years	1	0.39
	35–45 years	2	0.77
	45–55 years	37	14.29
	>55 years	219	84.56
Educational qualification (highest degree)	Bachelor's Degree	0	0.00
	Master's Degree	6	2.32
	Doctorate Degree (PhD)	253	97.68
The type of institution affiliated with	Central University	39	15.06
	State University	32	12.36
	Private University	12	4.63
	Central R&D Institute/Lab	137	52.90
	State R&D Institute/Lab	2	0.77
	Non-Government Organisation	13	5.02
	Private Company	4	1.54
	Other	20	7.72
Current (if retired, then the last) primary position	Director/Head of institution or above	64	24.71
	Department Head/Group Leader	68	26.25
	Scientist	31	11.97
	Professor/Lecturer	93	35.91
	Scientific/Technical Staff	1	0.39
	Other	2	0.77

Table 1 (continued)

Demographic variables		Frequency	Percentage
Research experience (in years)	< 10	0	0.00
	10–20	6	2.32
	20–30	43	16.60
	> 30	210	81.08
Peer-reviewed research publications	< 20	2	0.77
	20–40	9	3.47
	40–60	25	9.65
	60–80	31	11.97
	80–100	32	12.36
	> 100	160	61.78
Broad disciplines for current area of research	Physical Sciences	48	18.53
	Chemical Sciences	19	7.34
	Biological Sciences	91	35.14
	Mathematical Sciences	26	10.04
	Computer and IT	10	3.86
	Earth and Planetary Sciences	18	6.95
	Medical Sciences	20	7.72
	Engineering and Technology	24	9.27
	Humanities and Social Sciences	3	1.16
Fellow of the academy*	Fellow of IASc	Fellow of INSA	Fellow of NASI
	147 (56.76%)	121 (46.72%)	198 (76.45%)

*Many respondents expressed that they were fellows of more than one academy

Table 2 The overall frequency of scientists' involvement in public engagement (PE) activities and the affiliated institutions organizing such activities, and significant differences by control variables (expressed as percentages of respondents)

		Never	Rarely	Occasionally	Often	
Overall frequency of PE activities, in general, by …						
Individual scientists		0.77	10.81	49.03	39.38	
Scientists' institutions		2.32	13.90	47.49	36.29	
Variable	Factor	Never	Rarely	Occasionally	Often	Chi-square test
Overall PE by Individual scientists	Peer-reviewed publications					$\chi^2 = 29.042$ df = 15 $p = 0.016$
	< 20	0.00	0.00	0.00	0.00	
	20–40	11.11	11.11	44.44	33.33	
	40–60	0.00	12.00	40.00	48.00	
	60–80	0.00	22.58	58.06	19.35	
	80–100	3.13	9.38	53.13	34.38	
	> 100	0.00	8.75	47.50	43.75	
Overall PE by Scientists' institutions	Type of affiliated organization					$\chi^2 = 34.301$ df = 21 $p = 0.034$
	Central R&D Inst./Lab	0.73	10.22	45.99	43.07	
	Central University	5.13	25.64	48.72	20.51	
	NGO	7.69	7.69	38.46	46.15	
	Private Company	0.00	50.00	50.00	0.00	
	Private University	0.00	0.00	66.67	33.33	
	State R&D Inst./Lab	0.00	0.00	50.00	50.00	
	State University	6.25	25.00	34.38	34.38	
	Other	0.00	5.00	70.00	25.00	
	Area of research					$\chi^2 = 43.986$ df = 24 $p = 0.008$
	Biological Sciences	3.30	13.19	46.15	37.36	
	Chemical Sciences	0.00	15.79	57.89	26.32	
	Computer and IT	0.00	40.00	50.00	10.00	
	Earth and Planetary Sci	5.56	5.56	72.22	16.67	
	Eng. and Technology	0.00	8.33	62.50	29.17	
	Humanities-Social Science	33.33	0.00	33.33	33.33	
	Mathematical Sciences	3.85	15.38	53.85	26.92	
	Medical Sciences	0.00	15.00	45.00	40.00	
	Physical Sciences	0.00	14.58	27.08	58.33	

gave interviews to journalists/reporters (37.07%), never wrote popular science articles/books (35.52%), never wrote about science online (65.25%), and never shared research videos online (72.20%). Top two instances where scientists engaged more than six times were 'talking at schools and colleges' (27.41%) and 'face-to-face interactions' (20.85%).

If we make it never versus all frequencies (i.e., once, 2–5 times and 6+ times), the majority of respondents participated at least once in all the traditional ways of public engagement during the last year: face-to-face interactions (78.76%), talking at schools and colleges (88.03%), giving interviews to journalists/reporters (62.93%), writing popular science articles/books (64.48%) while the majority of them never used the online modes of

Table 3 Frequency of scientists' participation in the given six science communication activities during the last year and significant differences by control variables (expressed as percentage of respondents)

	Never	Once	2–5 times	6 + times
Face-to-face interactions with the public (open days/public talks/expos)	21.24	17.37	40.54	20.85
Talking at schools and colleges	11.97	18.92	41.70	27.41
Giving interviews to journalists/reporters	37.07	23.55	30.89	8.49
Writing popular science articles/books	35.52	23.94	33.20	7.34
Writing about science online (websites, blogs, social media)	65.25	12.74	18.15	3.86
Sharing research videos online	72.20	12.74	10.04	5.02

Variable	Factor	Never	Rarely	Occasionally	Often	Chi-square test
Writing about science online	Type of Affiliated organization					$\chi^2 = 39.698$ df = 21 $p = 0.008$
	Central R&D Inst./ Lab	64.23	13.14	18.98	3.65	
	Central University	84.62	0.00	7.69	7.69	
	NGO	46.15	15.38	30.77	7.69	
	Private Company	50.00	25.00	25.00	0.00	
	Private University	41.67	50.00	8.33	0.00	
	State R&D Inst./Lab	50.00	50.00	0.00	0.00	
	State University	53.13	15.63	28.13	3.13	
	Other	85.00	0.00	15.00	0.00	

communication with 65.25% never wrote about (popular) science online and 72.20% never shared a video about their research online. It shows that talking at schools and colleges remained the most popular way of public engagement, while sharing research videos online was the least popular among the senior Indian scientists who participated in the study.

A series of paired Chi-square tests of independence were conducted between the given six modes of public communication used by scientists and their demographic variables. From these tests, the only science communication activity showing statistically significant differences was 'writing about science online' with the type of affiliated organization, χ^2 (21, $N = 259$) = 39.698, $p < .01$ (as shown in Table 3). However, the effect size was moderate, with Cramer's V = 0.226. Here, a key difference observed is a considerable number of the respondents from central R&D institutions (18.98%), NGOs (30.77%), private companies (25.00%), state universities (28.13%) and others (15.00%) 'occasionally' wrote about science online when most of them across affiliations 'never' or 'rarely' did so.

How easy/difficult is public engagement?

The highest proportion of respondents (36.68%) said that engaging in science communication activities was fairly easy, while about 28% remained neutral (Table 4). When 'very easy' and 'fairly easy', and 'very difficult' and 'fairly difficult' responses were merged as 'easy' and 'difficult' respectively, almost double the respondents (45.95%) found it 'easy' than those who saw it 'difficult' (26.25%). However, only a very small percentage of the

Table 4 Scientists' perceptions and attitudes about their participation, performance, and overall experience in science communication activities, and correlation of scientists' frequency in PE activities with these variables (expressed as percentage of respondents)

Variables	Very difficult	Fairly difficult	Neutral	Fairly easy	Very easy
Ease/difficulty of engaging in science communication activities	2.70	23.55	27.80	36.68	9.27
	Very Bad	Bad	Average	Good	Very good	No opinion
Overall experience in science communication activities so far	0.00	1.54	18.15	33.20	40.54	6.56
	Very unlikely	Quite unlikely	Neutral	Quite likely	Very likely
Likelihood of getting involved in science communication activities in the future	1.54	5.02	16.22	50.97	26.25
	Very poor	Poor	Average	Good	Very good	No opinion
Rate your own engagement in science communication with the public/media	1.93	12.36	30.89	25.10	27.41	2.32
Personal variables for PE performance	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I personally enjoy taking part in science communication activities	1.54	0.77	18.15	51.35	28.19
I am confident about my ability to communicate science	0.39	0.77	13.51	49.03	36.29
I am personally well equipped to communicate my research	1.16	1.54	16.22	47.10	33.98
Correlation of scientists' likelihood to engage in PE in the future with different variables					Spearman's ρ
I personally enjoy taking part in science communication activities					0.595***
I am confident about my ability to communicate science					0.504***
I am personally well equipped to communicate my research					0.429***
Ease/difficulty of engaging in science communication activities					0.385***
Overall experience in science communication activities so far					0.403***
Scientists' overall frequency of PE activities					0.458***
Rate your own engagement in science communication with the public/media					0.420***

*$p < .05$, **$p < .01$, ***$p < .001$

respondents said that participating in PE activities was very difficult (2.70%) or very easy (9.27%).

Overall experience in science communication

When asked how their overall experience was so far if they had engaged in any science communication activities in the past, about 74% of respondents said it was either very good or good (Table 4). It was followed by about 18% saying it was average, with only about one and a half percent saying it was bad. Interestingly, no one said that their science communication experience was 'very bad,' with about 7% having 'no opinion' in this regard.

Rating own science communication engagement

When asked how you would rate your own engagement in science communication with the general public or the media, about 53% of the respondents rated their engagement as good or very good, with about 31% rated it as average, about 14% as very poor or poor, and about 2% expressed 'no opinion' (Table 4).

Personal variables for science communication performance

Three personal variables (personal enjoyment, confidence in communication abilities, and personal well-equippedness to communicate science), which can potentially affect scientists' performance in science communication activities and their willingness to engage in the future, were measured by asking them to show their agreement/disagreement with the given three statements. The majority of respondents agreed that they personally enjoyed taking part in science communication activities (79.54%), they were confident about their ability to communicate science (85.32%), and they personally felt that they were well-equipped to communicate their research (81.08%). Only about 1–3% showed disagreement, with about 14–18% remained neutral to these statements (Table 4).

Attitudes toward the possible impact of scientists' public engagement

Six scale items were used to assess the respondents' attitudes toward the possible impact of their engagement in science communication activities (Table 5). For simplicity, 'quite likely' and 'very likely' responses were merged as 'likely,' and 'quite unlikely' and 'very unlikely' responses as 'unlikely.' About 85% of the respondents expressed that their engagement in science communication activities would likely increase the scientific knowledge of the public, with 10% neutral and about 4% unlikely. Similarly, the majority of respondents said that their engagement would likely increase their own scientific knowledge (63.71%), their confidence in public communication (76.83%), provide scientific information for wider public use (86.49%), and popularize their research (62.93%). However, a relatively lower percentage but still most of the respondents (44.02%) expressed that their engagement would increase public support for their research, with 38.22% remaining neutral to this statement. Also, a considerable number of respondents remained neutral in the case of their engagement increasing their own scientific knowledge (23.55%), popularizing their research (27.03%), and increasing their confidence in public communication (16.99%). All these variables show a statistically significant positive correlation with

Table 5 Attitudes of Indian scientists toward the possible impacts of their engagement in science communication activities (expressed as percentage of respondents) and the correlation of impact variables with scientists' likelihood to engage in PE in the future

	Very unlikely	Quite unlikely	Neutral	Quite likely	Very likely
If you engage in science communication activities, then how likely do you think the following would happen?					
It will increase scientific knowledge of the public	1.16	3.09	10.42	63.32	22.01
It will increase my own scientific knowledge	6.18	6.56	23.55	43.63	20.08
It will increase my confidence in public communication	4.25	1.93	16.99	50.58	26.25
It will provide scientific information for wider public use	2.70	1.16	9.65	58.30	28.19
It will popularise my research	4.25	5.79	27.03	40.15	22.78
It will increase public support for my research	8.11	9.65	38.22	31.66	12.36
Correlation scientists' likelihood to engage in PE in the future with the above variables					Spearman's ρ
1. It will increase scientific knowledge of the public					0.487***
2. It will increase my own scientific knowledge					0.242***
3. It will increase my confidence in public communication					0.287***
4. It will provide scientific information for wider public use					0.444***
5. It will popularise my research					0.371***
6. It will increase public support for my research					0.278***

*$p < .05$, **$p < .01$, ***$p < .001$

scientists' likelihood to engage in PE activities in the future (Table 5). This suggests that scientists having positive attitudes toward the possible impact of their PE are more likely to get involved in science communication activities.

Likelihood to engage in the future

About 77% of the respondents said that they would likely (either 'quite likely' or 'very likely') get involved in science communication activities if they were given an opportunity to communicate their research with the public in the future (Table 4). Only about 7% expressed that they were unlikely (either 'quite unlikely' or 'very unlikely') to engage, while about 16% chose to remain neutral.

Further, all the above-mentioned variables (personal enjoyment, confidence in abilities, well-equippedness, ease/difficulty in engagement, overall experience, overall PE frequency, and rating of own engagement) showed a statistically significant correlation with the respondents' likelihood to engage in science communication activities in the future ($\rho = 0.385–0.595$, $p < .001$) (Table 4). This suggests that if scientists had positive views and attitudes toward their personal enjoyment, communicative capabilities, previous engagement, and experiences in science communication activities, they were more likely to participate in such activities in the future.

Discussion

Results suggest that almost all the respondents (99.33%)—senior and experienced scientists, with most of them occupying top scientific/administrative positions—participated in some kind of science communication activity during their careers. In this context, the findings of a survey in the UK suggest that senior scientists were more likely to engage with the public (Bauer & Jensen, 2011; Royal Society, 2006). A study of French scientists also suggests that the more senior a scientist is in the institutional hierarchy, the more active she/he is in public engagement (Boltanski & Maldidier, 1970, as quoted by Bauer & Jensen, 2011). This may be because scientists occupying senior scientific and administrative positions in scientific establishments are more required to or more exposed to engaging with non-scientist audiences as part of their job. However, most of the senior scientists in India surveyed (60%) participated only occasionally or rarely in PE activities, with less than 40% participating often. These results on Indian scientists' frequency of participation in PE activities are comparable to the findings from similar surveys in UK (Hamlyn et al., 2015; Royal Society, 2006), Denmark (Nielsen et al., 2007), Argentina (Kreimer et al., 2011), USA (AAAS, 2015), Maxico (Merino & Navarro, 2019), and Lithuania (Valinciute, 2020) where the majority of respondents (scientists) engaged in science communication at least once in a year, but the frequency of their participation largely remained occasional. These comparisons suggest that the low frequency of scientists' participation in PE activities is not specific to India only. Scientists in other countries are also not very frequent in their public engagements. But this remains a potential question why scientists' involvement in science communication activities is low? Further studies should explore this question in international and national contexts. Especially in India, where constitutional and policy provisions exist for disseminating scientific information and inculcation of scientific temper, it is a curious case for further investigation to understand what prevents Indian scientists from being frequent public communicators?

Like the frequency pattern of individual scientists, almost the same is the case of the frequency with which respondents' affiliated institutions organized public engagement events. About 61% of the institutions organized such events 'occasionally' or 'rarely,' with 36% doing it often. These findings suggest that individual scientists were relatively more frequent in participating in PE activities than their affiliated institutions organizing such events. Individual scientists might be more active in their personal capacity or interest in communicating their research to the public. But to ensure consistent efforts in public engagement at both individual and institutional levels, what matters more is how S&T institutions recognize and value the importance of science communication. As believed by the respondents, anecdotal evidence also suggests that many S&T institutions in India do not pay much emphasis on science communication and outreach activities in general. This observation is echoed by a multi-institutional European study that noted that most research institutions in Europe lacked a culture of public engagement where efforts for engaging with the public are appropriately recognized, evaluated, and rewarded as an important part of the institutional profile and identity (Neresini & Bucchi, 2011). Also, an extensive study of public communication by 2030 research institutes across eight countries (Brazil, Italy, Netherlands, USA, Germany, Portugal, UK, and Japan) revealed that science communication is taken for granted by most research institutes (Entradas et al., 2020). This observation by Entradas et al. (2020) concurs with what Indian scientists believed about how frequently their affiliated institutions organized public engagement events (as discussed above). The findings of these two studies (Entradas et al., 2020; Neresini & Bucchi, 2011) suggest that science communication largely remains a low-key area at the institutional level across countries and institutions and is yet to become a fully instituted activity that is well recognized and valued.

In this context, the current findings from a sample of elected fellows of three Indian national science academies also provide a similar picture of science communication as a low priority area in Indian R&D institutions. This calls for actions at the institutional level giving due importance to science communication and creating an encouraging ecosystem where contribution to establishing a dialogue between science and society is valued and rewarded. Such institutional actions may include updating institutional policies giving high priority to science communication, training scientists and other staff for effective public engagement and media interactions, establishing science communication and outreach units with specialized science communication professionals, inspiring scientists to engage with the public, and incentivizing/rewarding such initiatives (Burchell, 2015). An institutional mandate giving priority to science communication would mean allocating more resources for science communication and more institutional support for scientists' active engagement (Entradas et al., 2020). When scientists are not expected to communicate by their institutions, their frequency of participation or willingness to participate is expected to be relatively low. In such instances, their public involvement would be predominantly because of their personal interests or reasons. However, the availability of institutional policies, professional communicators and funding at the institutional level is expected to increase scientists' frequency of engaging in science communication activities (Entradas et al., 2020). Also, institutional level support is necessary for science outreach and engagement to flourish and boost scientists' participation (Lunsford et al., 2006).

When it comes to individual scientists' communication behaviors, face-to-face interactions and talking at schools and colleges were the most frequently used ways of communication by the majority of respondents, while engaging through popular media/press were moderately used, and online modes of communication were the least used by the respondents. Here, the finding that most Indian scientists used face-to-face or direct

communications/talks as the most preferred way of science communication with online modes as less used ways of communication is largely congruent with previous studies in UK (Hamlyn et al., 2015; Royal Society, 2006), Denmark (Nielsen et al., 2007), Argentina (Kreimer et al., 2011), China (Jia & Liu, 2014), USA (AAAS, 2015), and Maxico (Merino & Navarro, 2019). However, the majority of respondents had face-to-face interactions with the public (79%), talked at schools and colleges (88%), gave interviews to journalists (63%), and wrote popular science (64%) at least once during the last 1 year. On the other hand, most of them never wrote about popular science online (65%) or shared videos online about their research (72%). Face-to-face interactions and talking at schools and colleges were the top two ways of public engagement used by many respondents (> 20%) more than six times during the last year; comparable to 20% of US-based scientists engaging more than six times in face-to-face interactions (Dudo et al., 2014, 2018). About 63% of our respondents saying that they gave interviews to journalists/reporters is comparable with the findings of Peters et al. (2008) where nearly 64% of the surveyed scientists from the United States, Japan, Germany, United Kingdom and France believed that they were interviewed by journalists. But more than one-third of the respondents never gave interviews to journalists (37%) or wrote popular science (36%) during the previous year. This suggests that most of the respondents—who are senior (85% aged more than 55 years) and experienced (81% having more than 30 years of research experience) scientists—were more comfortable with the traditional ways of direct interpersonal communication than indirect and mediated or online methods of public communication. These results are largely consistent with the findings of Dudo et al. (2014, 2018), where US-based scientists engaged with the public more through face-to-face interactions (59%) than through online platforms (48%) and the media (42%). Our finding of Indian scientists engaging more in face-to-face communications than through the media is also largely consistent with the public engagement behavior of US-based nanoscientists (Dudo et al., 2014). When online and digital communications are increasingly becoming commonplace, it is interesting to note that most respondents preferred traditional modes of public engagement. Further studies should evaluate if such communication behaviors are limited to the current sample of senior scientists or if it is a larger trend, even among younger scientists. It would be desirable to understand if senior scientists' low online PE activity is limited due to their inability to use online tools properly or otherwise.

Further, most respondents had positive perceptions about different aspects related to their involvement in science communication. A vast majority of the respondents who engaged in science communication activities believed they had a 'good' or 'very good' experience (74%). Here, the favorable experience of Indian scientists can be a greater motivator for their future engagements, as past behavior (engagement) is one of the important factors deciding scientists' intentions to engage in the future (Poliakoff & Webb, 2007). The perceived overall good experience of senior Indian scientists in science communication is comparable to the experience of US-based senior scientists being positive or very positive (Dudo et al., 2018), and to what Singapore-based experienced scientists believed that their participation in science communication activities was enjoyable, pleasant, and gratifying (Ho et al., 2020). Further, 88% of the Indian respondents believed their engagement was neither 'very difficult' nor 'very easy'. However, the majority of them (54%) being on the difficult or neutral side, with 46% of respondents finding it easy, suggests that there is still much scope for appropriate interventions for improvements and making it easier for scientists to engage with the public and enhancing the quality of their engagement, especially for those who could not rate their overall public engagement as 'good' or 'very good' (47%). However, the percentage of Indian scientists finding science communication

as 'fairly easy' or 'very easy' (46%) is lower than that of Argentine scientists (76%) who find it as 'easy' or 'very easy' (Kreimer et al., 2011), but it is higher than that of British scientists (35%) who find public engagement as 'fairly easy' or 'very easy' (Royal Society, 2006). As only 46% of the respondents believed science communication was easy for them, science agencies and institutional policies should focus on providing necessary communication and media training to scientists so that it becomes easier for them to communicate their research with the public.

However, the respondents were personally enthusiastic about their involvement and performance in PE activities. More than three-quarters of the respondents of this study believed that they personally enjoyed public engagement and were confident and well-equipped to communicate their research. These are important factors in deciding willingness to engage more and perform better in science communication. Here, more Indian scientists (81%) believed that they were well-quipped to communicate science with the public than British scientists (51%) (Royal Society, 2006). Also, Ho et al. (2020) reported that enjoyment and perceived efficiency are potential factors shaping Singapore-based scientists' willingness to engage in science communication activities. These personal variables (enjoyment, confidence and well-equippedness) play an important role in making someone engage in any activity, including public engagement, and ensure higher performance and effectiveness.

We noticed that the Indian respondents showed encouraging attitudes toward the possible impacts of their engagement in science communication activities. The majority of respondents believed that their engagement in such activities would increase the scientific knowledge of the public, their own scientific knowledge, and their confidence in public communication, provide scientific information for wider public use, and popularize their research. But the majority did not believe that it would increase public support for their research. These positive attitudes should motivate scientists to engage more often, and their engagement helps the public audiences understand complex scientific topics and make informed decisions (Shugart & Racaniello, 2015).

Further, it is interesting to note that a vast majority of the respondents (77.22%) expressed that they would engage in the future if opportunities were provided. This finding is comparable to 76.60% of Mexican scientists expressing their interest in science communication (Merino & Navarro, 2019) and to almost all Chinese scientists interviewed expressing a willingness to participate in public engagement (Zhang, 2015). This result is also consistent with the majority of the American scientists associated with seven scientific societies (Besley et al., 2018) and most of the scientists related to the University of Manchester, UK (Poliakoff & Webb, 2007) expressing their willingness to engage. When most of the scientists surveyed in India and other countries are willing to engage, but practically, most of them engage only occasionally or rarely, it suggests that they are mostly willing to engage but are largely not very active in science communication activities. This reaffirms the 'willing but inactive' phenomenon earlier observed by Zhang (2015) based on in-depth interviews of Chinese scientists. It suggests that many scientists believe that they have a social responsibility to engage with the public and are even willing to accept that scientists should contribute to public communication of science, but due to different reasons, many of them are not able to contribute actively in such activities. The results of our study are also consistent with the findings of a survey of Chinese scientists, where the majority of respondents (94%) agreed that science communication is their responsibility, but the majority did not contribute in action (Jia & Liu, 2014). This peculiar situation where scientists are willing to engage but are practically less active in science communication requires the attention of science communication scholars, science/funding agencies

and policymakers. Further research should focus on understanding why scientists are not very active when they are willing to engage, how their willingness can be translated into active involvement, and what is preventing them from actively engaging with the public despite their willingness to do so. Factors and hindrances in scientists' active participation in PE should be identified, and accordingly, appropriate institutional and policy interventions should be implemented for enhancing scientists' engagement.

By applying the theoretical framework of the theory of planned behavior (Ajzen, 1991), Poliakoff and Webb (2007) have demonstrated that scientists' intentions to engage in science communication activities are influenced by their past behavior, attitudes, perceived behavioral controls, and descriptive norms. From the above discussion, we find that Indian scientists have positive perceptions and attitudes toward their own involvement in science communication activities, their experience, performance, and capabilities to do such activities, and are largely aware of the possible impacts of their science communication engagements. Several of these factors were found to be positively correlated with the respondents' likelihood to engage in the future. This provides a firm ground suggestive of Indian scientists' readiness and willingness to engage and contribute more to science communication and public dialogue. However, despite having favorable experience, attitudes, perceived capabilities to perform, and awareness about the possible impacts of their public engagement, the actual frequency of participation in science communication activities by most Indian scientists (60%) has remained to be occasional or rare. Despite such encouraging contexts, it remains unclear why the overall frequency of most respondents was low. Identifying the possible and specific hindrances and barriers in science communication by Indian scientists would help enhance their public engagement. Understanding what encourages and incentivizes them to participate in PE would further inform future policies on scientists' public engagement. Accordingly, appropriate practical and policy interventions at national and institutional levels would be required to encourage more scientists to engage or find ways to enhance the participation of scientists who are already willing but not active in science communication.

Further, it is found that scientists' science communication perceptions, attitudes and communication behaviors were largely independent of their demographic characteristics: age, gender, education, primary position, affiliation, research experience, number of publications, and area of research. Such a weak association is possibly due to the current sample mainly consisting of senior and experienced male scientists who occupy top positions in the hierarchy, with slight variation in demographic/control variables. Therefore, studies with larger samples, including younger researchers and more diversity in demographics, would help get a better understanding of what Indian scientists think about science communication and its association with demographic variables. Further studies should go beyond scientists' self-reported responses and investigate the ground reality of science communication at individual and institutional levels in the Indian R&D system by examining their actual involvement in PE activities, frequency and scale, with reference to the institutional mandates and policies (if any) for science communication.

The findings of the current study also provide evidence from India that the calls by different stakeholders for more engagement by scientists (e.g., Dudo & Besley, 2016; Nisbet & Scheufele, 2009; Royal Society, 1985, 2006; Wellcome Trust, 2001) are well placed and also provide context for the recent push by the Indian government to R&D institutions and individual scientists to be more open and engage more with the public (Government of India, 2018; Press Information Bureau, 2017; Rajput, 2018). Also, as discussed in the introduction, the Indian government's recent policy initiatives (Department of S&T, 2019, 2020) are laying greater emphasis on science communication, including mandatory 10

days of public engagement per year by scientists and giving appropriate credit for the same in scientists' promotion and annual appraisals. Such policy provisions and incentives are being seen in the right direction and, if appropriately implemented, are expected to encourage Indian scientists to engage more and improve the science communication landscape in the country (Rajput, 2019; Rajput & Sharma, 2021). However, such policy initiatives would be more effective and useful if guided by strong empirical evidence suggesting what Indian scientists think about and expect from engaging in science communication activities. We hope that the current findings will be helpful in this direction and stimulate further research.

Limitations and future research

This study has some limitations as it examined the views and attitudes of only the senior and experienced Indian scientists who were elected fellows of three Indian national science academies when the survey was conducted. Scientists (even the senior ones) and the early and mid-career scholars and researchers who were not elected fellows of the selected three science academies at that time were excluded from this study. This means that our results are based on a sample of relatively senior and experienced scientists, with more than 50% of them occupying senior and top managerial and administrative positions in different scientific establishments. The scope of this study was to generate some baseline data about top Indian scientists' perspectives on science communication that can guide young researchers and further research on this topic. Also, as the participation in the study was voluntary, there are chances that more scientists holding positive attitudes about or favorable experience in science communication took part in the study. These limitations might restrict the generalizability of the findings to the entire Indian scientific community. These findings cannot be generalized beyond the characteristics of the sample as we do not have any trustworthy insights about what sense junior scientists in India make about science communication and its relevance. The limitations of the current study offer opportunities for future research with larger sample size, including young researchers as well, to advance our understanding of how Indian scientists engage in science communication activities.

Conclusion

This exploratory study provides a snapshot of Indian scientists' perceptions, attitudes and communication behaviors in science communication. It explores what Indian scientists think about their involvement, performance, experience, and willingness to engage in public engagement activities and the perceived impact of their engagement on scientists, their research and society. Our study provides empirical evidence that almost all the respondents have participated in some kind of science communication activity during their careers. Similarly, a vast majority of their affiliated institutions have organized such events. However, most scientists and their institutions participated in or organized such events 'occasionally', while the number of those who did it often is not very high. Scientists were relatively more frequent in public engagement than their affiliated institutions organizing such events.

A vast majority of Indian scientists believed that they had a positive experience in the public communication of science which they found was neither 'very difficult' nor 'very easy', while expressing their willingness to engage in the future as well. The majority of

respondents rated their own engagement in science communication activities as good or very good. More than three-quarters of the respondents personally enjoyed participating in science communication while feeling that they were confident and well-equipped to communicate their research. Concurrent with the literature, most respondents were more comfortable with face-to-face interactions than mediated or online ways of public communication. They also expressed positive attitudes about the impact of their participation in science communication and believed that it would provide scientific information for wider public use while increasing their scientific knowledge. They also believed that it would increase their own scientific knowledge and confidence in public communication.

While filling an important gap in the literature and providing first-ever empirical evidence from India, these findings would inform the future policies on science communication by scientists in India and guide appropriate interventions for enhancing their participation in public engagement. Results suggest that respondents' positive perceptions, attitudes and previous communication behaviors have an effect on their likelihood to participate in PE activities in the future. However, when the majority of senior Indian scientists in this study are optimistic about their engagement, capabilities, performance and experience in science communication, are willing to engage in the future, and have positive attitudes toward the impact of their engagement; their overall low frequency of engagement invites further investigation.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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