Chapter 2

Literature Review

2.1. Introduction

In this chapter, a review of the literature related to the current study on science communication by scientists in the Indian context, with some background understanding of the relevant concepts, theory, and practices surrounding science communication, is presented. As science communication by scientists is not explored much in India, the literature review on scientists' views, perceptions, attitudes, experiences, and practices related to science communication relies on much of the work done in other countries. An attempt is made to present an overview of science communication as it evolves through ups and downs and the dominant science communication approaches and models. The relationship among science, society, and culture is brought out with particular reference to Indian science policies. The interaction of science and the media and the related opportunities and tensions faced are discussed. While evaluating scientists' views on science communication and how they see their involvement in it, what factors and barriers prevent their active involvement with the public, how engagement impacts career advancement and training in science communication are also explored in the extensive literature review.

2.2. Science communication: An overview

A few decades ago (the mid-1980s), a movement for public understanding of science was started in the West to increase the public's general knowledge of science (Mulder, Longnecker & Davis, 2008; Miller, 2001). Now, this movement has spread all over the world. It got much momentum with the publication of the 'Public Understanding of Science' report by the Royal Society (1985) in the UK. The report strongly recommended increasing

public understanding of science, with an active role of scientists in disseminating scientific information to the larger society. It states, "our most direct and urgent message must be to scientists themselves: learn to communicate with the public, be willing to do so, and indeed consider it their duty to do so." It was primarily inspired by the fact that the public is largely ignorant about scientific advances, and such ignorance is a primary reason for public hostilities toward science. Scientific ignorance is seen as a big challenge in our personal, social, and national well-being and development. Such ignorance is also the cause of various myths, superstitions, and blind faiths, which can further hinder the development plan. It can also lead to public opposition to scientific advances and projects (Bubela et al., 2009; Rajput, 2017). Much of the public opposition to science is based on misinformation most fuelled through inappropriate media coverage of science (Gregory, 2003; Bucchi & Trench, 2016). This situation requires institutional efforts for an acceptable range of science in popular media (Dornan, 1990; Wynne, 1991).

The public understanding of science draws its motivation from the idea that the deficit of scientific knowledge in the public influences their perceptions and attitudes toward science which can be changed by providing more scientific information (Short, 2013). Several studies have noted that scientific illiteracy among the public and lack of public engagement on the part of scientists is considered among the main reasons for lack of public understanding about science (Hartz & Chapell, 1997, Treise & Weigold, 2002, Lundy, Ruth, Telg & Irani, 2006). In the presence of such a chasm between science and society, a slight miscommunication or misrepresentation can lead to avoidable and unnecessary controversies. On the other hand, controversies are also potential opportunities for ensuring better dialogue and more engagement between science and society. Several controversies surrounding science and its communication have attracted much attention from stakeholders, including policymakers,

politicians, bureaucrats, academic researchers, social activists, the general public, and the media. Scientists and science communicators are required to use these opportunities to spread scientific awareness among the public, create better relations between science and society, ease public opposition to science, and build public trust in science.

Further, new scientific knowledge is being generated in the name of 'for the betterment, advancement, and welfare of society.' However, much of this knowledge is not reaching the public (at least, the way it should). It is a general perception that scientists mostly communicate their research among themselves and rarely engage with the public. When scientists proactively and actively engage in peer-to-peer communications (or communication among the experts), their engagement with the general public is not as frequent as expected. Such lack of communication creates a knowledge gap making scientists 'science rich' and the public 'science poor,' resulting in two cultures (Snow, 1959). This ever-widening gap can potentially lead to public disconnect and trust deficit, with the possibility of creating anti-science sentiments in the public. Therefore, there is a need to connect science with society by filling the communication gap and building public confidence and trust in science. Gregory (2003) says, "Where knowledge is lacking, trust is essential. Where trust is lacking, knowledge is essential." Therefore, the public's trust in science can be gained only through sharing scientific knowledge with the public and engaging them with science. Science communication efforts are also intended to address the declining public confidence in science (Stilgoe, Irwin & Jones, 2006), which can be achieved through more openness and transparency on science and scientists (Gibbons et al., 1994; Hulme & Ravetz, 2009). Enhancing public understanding of science is also essential to counter anti-science and non-rationality (Short, 2013). To generate a scientifically aware citizenry, communication

between science and society is necessary. Now, this communication may also include science popularization, outreach, and dissemination activities.

Products of science and technology are already surrounding us and are affecting us to become an integral part of our daily lives. Today, we cannot think of living without S&T and its products. We have developed significant dependence on S&T interventions for our needs (Priest, 2010). Such a situation also necessitates that we have know-how about the various products of S&T that surround us and that we use daily, only to use these products more efficiently and effectively. Therefore, this requires regular dissemination of scientific information and engagement activities to increase public awareness about science (Government of India, 1958; Royal Society, 1985; Dornan, 1990; Wynne, 1991).

Interestingly, this emerging field is known to different people by different names, for example, Public Understanding of Science (PUS), Public Understanding of S&T (PUST), Public Communication of Science, Public Science Communication, Public Communication of S&T (PCST), Public Awareness of Science (PAS), Scientific Literacy (SL), Scientific Awareness (SA), Science Dissemination, Science Outreach, Science Popularisation, Public Engagement with Science (PES), Science in Society (SiS), Public Engagement with S&T (PEST), Public Engagement, and Science Communication. (Burns, O'Connor & Stocklmayer, 2003; Bucchi & Trench, 2016; Rajput, 2017). Burns, O'Connor & Stocklmayer (2003) have even tried to define several of these terms. However, global scholarship is slowly but increasingly accepting the term 'science communication' for describing this area of expertise.

The earlier movement for increasing understanding of science among the public has given immense impetus to the growth of science communication as an academic discipline and

professional expertise around the world. Science communication is increasingly becoming popular among scientists across scientific disciplines and the media outlets as well. This emerging field also attracts academicians from humanities, social sciences, journalism, mass communication, management, and natural and engineering sciences.

Science communication, in simple terms, is the communication of science and scientific practices among non-scientist audiences or the general public. It tries to connect science with society by creating effective and efficient messages/communications for public consumption and creating interventions and avenues for disseminating scientific information to the public, public dialogue and engagement with science, science in society, and public participation in science. The popularisation of science is being realised by using every possible and available means of communication. To reach the large society as quickly as possible, the various means of mass communication or mass media are the top priority of communicating science to the public.

However, when communication of science through the media is marred with several issues such as misquoting, misreporting, misrepresentation, and factual inaccuracies (Dornan, 1990; Wynne, 1991), the demand from different quarters of society for an active role of scientists is desired (Bucchi & Trench, 2016). There are frequent calls from the members of the public, policymakers, politicians, scientists, science managers, and science communication scholars for an active role and more involvement of scientists in public communication of science (e.g., Royal Society, 1985; Wellcome Trust, 2001; Royal Society, 2006; Nisbet & Scheufele, 2009; Agre & Leshner, 2010; Shugart & Racaniello, 2015; Dudo & Besley, 2016).

2.3. Why science communication?

Before further discussing science communication, it is crucial to understand why we need to communicate science? Why should scientists do this? Science is a massive enterprise of human endeavour to understand nature better and utilize the knowledge so gained effectively and efficiently for the betterment, advancement, and welfare of human society (Rajput, 2017). Today, huge scientific expertise/knowledge has been created but remains buried in the technical jargon in research laboratories/libraries. This knowledge needs to be liberated from the shackles of jargon and presented to the public/society in a form and language easily understandable (Davis, 2010). Such understanding of scientific knowledge by the public would help them appreciate scientific advances while also using these appropriately.

Much of the prescriptive literature on science communication for filling the public's knowledge deficit has discussed this topic. Several reasons have been provided why science communication with the public or public understanding of science is essential. One of the main reasons frequently highlighted for communicating science to the public is that much of the science is being done at public-funded R&D institutions, funded by governments through the taxpayers' money. When taxpayers fund scientists' research and salary, they have the right to know what research is being done with their money. This public funding mandates an obligation on the part of scientists and scientific institutions to inform the public of their research and development (R&D) activities or projects and the social, ethical and economic implications of these advances on the larger society. Here, it is understood that scientists know what is happening in the world of science, but the public is seen as ignorant of it. In fact, scientific illiteracy among the general public was the main reason that led to the 'public understanding of science' movement in the early 1980s in the West (Royal Society, 1985), which has evolved now as science communication and public engagement.

Another point is that science and society do not exist in total isolation but are closely related. Much of the science is being done to benefit the human community by solving prevalent problems or preparing for imminent crises in the future. This requires taking the benefits of science to society for the more significant social welfare. However, this cannot be achieved if there is no communication between science and society. Scientists use the specialised terminology of their field, while the public uses the common vocabulary. Appropriate science communication interventions are needed to help scientists and the public talk to each other or understand each other. The language used in scientific papers or talks by scientists is almost alien to the general public. There is a need to churn it down to the intended audience's level and communicate it in such a language that the general public can understand and appreciate (Royal Society, 1985; Ahteensuu, 2012; Besley, 2015). This churning down leads to another objective of science communication as 'to simplify or explain science to the public,' which is different from formal science education. Better informing the public about science is considered an objective of science communication by most scientists in the US (Rose, Markowitz & Brossard (2020).

Educating or informing the public by simplifying science feeds to the larger aim of commonising science and scientific thinking or culture among the masses to create a scientifically aware citizenry. In this connection, the term 'scientific temper' is widely used in India, which J.L Nehru first introduced as "a way of life, a process of thinking, a method of acting and associating with our fellowmen" (Nehru, 1946). It is a buzzword in science communication/popularisation circles in India. One of the main aims of science communication is to inculcate scientific temper among the masses. Even the Indian Constitution requires inculcating scientific temper as a fundamental duty of every citizen

(Part-IV of the Constitution of India, Article 51 A(h)). Many scholars have tried to define and refine it further. Those unfamiliar with this popular Indian term may see its rough equivalents as scientific thinking, scientific attitude, or scientific temperament.

Having a scientific temper is not equal to having scientific knowledge (Rautela & Chowdhury, 2016). Instead, it reflects one's logical, rational and analytical thinking, systematic and orderly way of performance in all spheres of life (Rautela & Chowdhury, 2016). Another researcher sees scientific attitude as "a state of mind that enables creative thinking about Nature and natural phenomena, and engaging in valid scientific research on these phenomena" (Arseculeratne, 2014).

Singh, Dogra & Singh (2016) define scientific temper as "a temperament which connotes a type of frame or disposition of mind which is free from superstition, prejudice, rigidness, obscurantism, close-mindedness, irrationality, un-innovativeness, subjectivity and other parochial tendencies."

Concerning scientific temper, Dhar (2009) says, "We consider such a person, who imbibes the essence of the scientific method in his outlook, and uses it in his everyday life, as possessing Scientific Temper." He further adds that "scientific temper, or scientific attitude is characterized by the traits: Healthy scepticism, Universalism, Freedom from prejudice or bias, Objectivity, Open mindedness and humility, Willingness to suspend judgement without sufficient evidence, Rationality, and Perseverance - positive approach to failure" (Dhar, 2009).

So, making it simple, inculcating scientific temper is about developing a mind powered by scientific thinking and logic to address our daily life concerns and problems scientifically. It refers to a mindset that is open to know/seek the truth through scientific, rational and logical ways while being ready to change with the arrival of new evidence through the scientific method.

Another reason for popularising science among the masses is to boost science-society interactions and public participation in science to foster public trust in science and scientists (Irwin, 1995; Gregory & Miller, 1998; Royal Society, 2006). It is to allow the public to engage with science and scientists with the public. When scientists and the public interact frequently, it creates an atmosphere of transparency and mutual trust among the two, which is beneficial for advancing science and society's welfare. It also contributes to creating a scientifically aware citizenry capable of making informed decisions in their lives (Bauer, Allum & Miller, 2007; Miller, 2004). However, the interaction between science and society is complex (Martin, 2016, p.19) and is faced with several challenges and problems, including public distrust in science (Gregory & Miller, 1998; House of Lords, 2000). Several attempts have been made to understand the possible reasons for public distrust, as Martin (2016) noted. Lack of communication between the two and critical attitudes among scientists and the public about each other may be major reasons. Scientists may think the public is ignorant and does not understand their research, while the public may think scientists are elites sitting in their ivory towers less interested in the public.

Also, to attract more people, especially students, to science, a need for creating excitement about science through regular engagements and personal involvement in science activities is highlighted. Exciting people about science and increasing public trust in science are

important science communication objectives (Royal Society, 2006; Rose, Markowitz & Brossard, 2020).

Governments and other agencies make policies related to science and society or impact science and society. Especially, the policies related to science and scientists require better-informed initiatives. Here, policymakers may not be experts on everything related to science, so it mandates active contributions from scientists/experts to help policymakers develop policies informed by scientific evidence. It also requires appropriate dialogue between scientists and policymakers. However, many scientists do not see policymaking as an area where they can contribute much or often.

Several studies have highlighted informing/educating the public, increasing public awareness, creating excitement about science, increasing science-society interactions, contributing to public debate and defending science, and building public trust in science as the main reasons for public science communication and scientists' involvement in it (Wellcome Trust, 2001; Dudo & Besley, 2016; Guerrero, 2016; Kreimer, Levin & Jensen, 2011; Rose, Merino & Navarro, 2019; Markowitz & Brossard, 2020; Valinciute, 2020). However, scientists' involvement in science communication is generally inclined toward informing, educating, or explaining science rather than contributing to policy or building public trust in science objectives (Dudo & Besley, 2016). This inclination is possible because scientists believe that the public lacks an understanding of scientific issues. Therefore, addressing this deficit is considered beneficial for the public (Wellcome Trust, 2001).

2.4. Defining science communication

In the simplest terms, science communication can be defined as the communication of science. As the terms 'science' and 'communication' are defined by different people differently, there is no single definition universally accepted by all. Similarly, different scholars have attempted to defined science communication in their own ways.

For example, Davis (2010) says science communication is broadly 'the popularisation of science.' He adds that the practice of science communication is to distill the scientific knowledge present in the technical language of science into a form the public can readily understand. It is an attempt to define science communication from the practice or process perspective. According to Brake & Weitkamp (2010), science communication is the communication of scientific information to public audiences.

Bucchi and Trench (2016) describe the term science popularisation as "a wide range of practices in making scientific information accessible to general, non-expert audiences" (p.153). Calling it as public engagement, Poliakoff & Webb (2007) also tried to define it as "any scientific communication that engages an audience outside of academia" (p.244).

Burns, O'Connor & Stocklmayer (2003) attempted to define science communication with an AEIOU vowel analogy (p.183). They define it as:

> the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the vowel analogy):
>
> A = Awareness, including familiarity with new aspects of science
> E = Enjoyment or other affective responses, e.g. appreciating science as entertainment or art
> I = Interest, as evidenced by voluntary involvement with science or its communication
> O = Opinions, the forming, reforming, or confirming of science-related attitudes
> U = Understanding of science, its content, processes, and social factors.

They further suggest that "science communication may involve science practitioners, mediators, and other members of the general public, either peer-to-peer or between groups." The definition forwarded by Burns, O'Connor & Stocklmayer (2003) is based on personal responses to science communication, and it ignores the practice aspect of science communication as contested by Davis (2010).

Science Communication is the "popularisation and commonisation of scientific knowledge, scientific temper, scientific method of enquiry and scientific culture among the masses" (Rajput, 2017, p.2266). By commonisation, it is meant that the intended thing (e.g., scientific knowledge) is commonly available and practicable. Appropriate mechanisms and interventions for active public engagement and two-way dialogue between scientists and society can be developed and used to increase the public understanding of science, and scientists' understanding of the publics to achieve such commonisation of science (Rajput, 2017).

Such interventions and mechanisms of commonisation may include all the varied modes and channels of communication: mass communication (print, electronic and digital: newspapers, magazines, books, TV/radio programmes, videos, documentaries, fiction/features, websites, blogs, etc.), public communication (lectures, talks, science shows, etc.), interpersonal communication, journalism, traditional modes of communication (*chopaals*, plays/drama, street plays, *melas*, exhibitions, museums, storytelling, etc.), multimedia, and new and social media. To construct effective science communication messages through any of these channels/modes of communication requires considerable expertise (professional touch) in handling the selected medium and its formats. It also requires a scholarly understanding of science communication, its process and the associated activities.

2.5. Models and approaches in science communication

Science communication has evolved both theoretically and practically, academically and professionally, over the past few decades. Theoretically and academically, it started with the notion that the public is ignorant of science (deficit of scientific knowledge) and needs to be educated about science through the dissemination of scientific information (Royal Society, 1985; Wynne, 1991; Miller, 2001; Burns, O'Connor & Stocklmayer, 2003; Gregory, 2003; Davies, 2008; Short, 2013). This approach to science communication says that there is a knowledge/information deficit among the public which can be filled by sermons by the science experts. This theoretical approach led to the practice of broadcasting science messages through mass media indiscriminately among the larger audience. This one-way, top-down approach of communicating science to the ignorant public by experts is popularly referred to as the 'deficit model' (Dornan, 1990; Wynne, 1991). In addition to lack of scientific information, the deficit model has another assumption that the public and politicians are often misinformed about science, fuelled mainly by inadequate and sensationalist media coverage of science (Gregory, 2003; Bucchi and Trench, 2016). The problem with this approach is that it treats all the audience as ignorant about science without considering any contextual or situational requirements. Many scholars have criticized this approach for lack of scientific knowledge being the only basis. In addition to the deficit, other factors such as culture, economic status, social values, and trust also need to be considered (Sturgis & Allum, 2004). Different scholars have tried to develop different theories, approaches, and models to address how science communication should happen.

It has been observed that context plays a vital role in any successful communication activity. Fox & Irwin (1998) argued that "the social, informational, motivational, and discourse

context in which beliefs are constructed, and statements are formulated provides myriad additional cues that influence what is expressed by speakers and what is understood by listeners" (p.57). Therefore, any effective communication requires an understanding of the context of the audience and the message to be communicated. This understanding led to the contextual approach in science communication which involves sharing science messages relevant to the audience with due consideration to their local contexts. Humans do not just respond to information but relate it to their circumstances, experiences, social, psychological, and cultural contexts (Brossard & Lewenstein, 2010). The contextual approach is a bit improvised version of the deficit approach. It just tries to disseminate scientific information while regarding the contextual settings of the audience. The public has local contexts, so science communication becomes a context-dependent process (Davies, 2008). Scientists should first understand these contexts through listening to the public and act accordingly (Gregory, 2003). In the contextual model, the public is seen as an active player contributing to the creation of scientific and local knowledge (Burns, O'Connor & Stocklmayer, 2003). However, this approach has also primarily remained as one-way, top-down traffic.

Another approach is lay expertise. According to Brossard & Lewenstein (2010), different scholars who favour the lay expertise approach of science communication believe that the public has their knowledge, experiences, and expertise about their local circumstances. For example, Wynne (1989) has emphasised that the public has their local knowledge or lay expertise. The proponents of this model say that while constructing science communication messages, it is essential to pay due attention to the local knowledge and expertise possessed by the target audiences, and that audience should not be considered empty vessels who need to be filled with new information. So the aim of science communication here is to expand further the knowledge and expertise of the audience (public). Different societies and cultures

have developed over the years and centuries their local knowledge systems, and those knowledge systems add to the intellectual development of the people (Studley, 1998; Briggs, 2005; Chikaire, J. et al., 2012; IASG, 2014; UNESCO, 2017). This approach is also criticised for giving more importance to traditional knowledge than modern scientific knowledge. 'Deficit,' 'lay expertise,' or 'contextual' all fall under the one-way 'deficit' information traffic where information-rich give sermons to the information-poor.

A more engaging two-way approach was needed to overcome the limitations of the deficit approaches to science communication. Here, the public is not a mere receiver of the one-way, top-down information traffic but also to have a say in the communication process and policy-related issues (Borchelt & Hudson, 2008). This new approach giving importance to the public as contributors in the communication process is called the 'dialogue model.' It was intended to allow two-way interaction between scientists and the public. However, it was also criticised for not having much dialogue where the public could have a greater say. Because when institutions are struggling to define their communicative approaches as being deficit, dialogue, or participatory, much of their efforts branded as dialogue or participatory end up being top-down sermons/lectures by the science experts (Bucchi, 2008, p.70). Also, scientists may not always be available to public dialogues, and they may also face difficulties from their employers to participate in such activities.

Another new approach emerged based on public engagement with or participation in science. Here, communication is not always in the top-down model but involves a two-way communication process where scientists and the public can exchange their views and interact responsibly. This public engagement model was intended to build public trust in science and to democratise science. Some scholars even move one step ahead and call that the public can

also be the co-producer of scientific knowledge, not just the 'deficit' consumer, through enhanced public participation in science. This approach is called the participatory model of science communication. It advocates the involvement of the public not just in the communication process but also at the knowledge production, governance, and policy levels. This approach also gave rise to citizen scientists and their citizen science movements. Such two-way equal participant approaches lead to the real and active dialogue or engagement between science and society. Such science communication can happen through public engagement activities such as meet the scientist, visits to labs, discussions, debates on science topics, science centres, science cafes, science museums, and science cities. The participatory model is also criticised for several reasons. Involving the public at every step of the scientific process may sound like democratising science, but it may disturb the real scientific investigations. Someone may argue that such a situation may politicise science. Such public participation may be carefully decided where it does not create any hurdles in the advancement of science.

From the above discussion, it appears that different approaches and models of science communication such as deficit, contextual, lay expertise, dialogue, public engagement, and public participation have evolved over the past few decades. These models constitute the dominant viewpoints on how science and society interact or should engage with each other. In this context, while relying on previous studies (Irwin, 2009; Logan, 2001; Stilgoe & Wilson, 2009), Roten (2011) has summarised the different approaches on scientist-society relations formulated over the past few decades into three dominant discourses. These three discourses are summed as:

- The knowledge *deficit* among the public requires scientists to *inform* them.

- The public's *negative attitudes* (distrust) resulting in distrust on science require scientists to *dialogue* with them.
- The public's *demand for openness and transparency* requires scientists to *engage/participate* with the public.

These three approaches of science communication are not exclusive but contribute to each other. All the three models of deficit, dialogue, and engagement are relevant in their place, although all of these have their own merits and demerits. We need all these approaches, with a certain balance, to achieve the different objectives of science communication. Especially, even after much criticism, the deficit model will always be required. Because for healthy dialogue, filling the deficit is an essential prerequisite (Dickson, 2005). Filling deficit and having healthy dialogue both are essential for meaningful engagement and active participation.

2.6. Science, society and culture: An Indian policy perspective

Scientists doing research come from society only, and science serves the larger society through problem-solving or addressing human curiosity to know. However, as discussed above, the gap between science and society is increasing due to a lack of communication. As every society has its own culture, so is the culture of science – scientific culture. There are 'two cultures' as suggested by Snow (1959). In addition to the gap in scientific knowledge, there are cultural differences between science and society.

Scientific knowledge is closely associated with societal and developmental issues. Its importance is reflected in these words "the most vital difference between developed and developing, rich and poor countries, is the knowledge gap – the capacity to generate, acquire,

disseminate, and use scientific and technological knowledge" (IRDC, 1991). Science, society, and culture are not distinct entities but are closely related, inter-related, and inter-dependent, complementing and reinforcing each other (Rajput, 2017). In fact, there is a symbiotic relationship where one is helping in the advancement of the other.

A close connection among science, technology, society, culture, and national growth and development has been nicely brought out in the Scientific Policy Resolution (SPR) 1958 – India's first science policy document soon after her independence. It states that large scale cultivation of science and use of its applications has the potential to provide "a standard of living and social and cultural amenities, which were once confined to a very small privileged minority of the population." SPR 1958 also values the interaction of science with society, culture, and civilisation by saying, "It is only through the scientific approach and method and the use of scientific knowledge that reasonable material and cultural amenities and services can be provided for every member of the community."

This policy emphasis suggests that the Indian government has been serious about cultivating science and spreading scientific knowledge to the larger society from the very beginning. The second science policy, 'Technology Policy Statement (TPS) 1983' of the Indian Government, was focussed on technology and technological aspects directed toward ensuring food, health, employment, energy, etc., but it does not fail to establish a science, technology, and society connect. It stresses using technology to meet people's aspirations, especially the weaker and backward sections of society. TPS 1983 advises that development plans should be based on our culture and local needs while focusing on uplifting common people. It also calls for the involvement of all people, especially the young minds, to solve our problems by applying the scientific method and temper.

Further, highlighting the relations among science, society, and culture, the preamble of the Indian Government's third science policy, 'Science and Technology Policy (STP) 2003,' states, "Science and technology have profoundly influenced the course of human civilisation. … Science and technology have been an integral part of Indian civilisation and culture over the past several millennia." While recognising the role of science and technology in national development, economic growth, and social well-being, the STP 2003 further adds that India has been committed to the 'task of promoting the spread of science' – an indirect reference to science communication. It also recognises that with knowledge becoming a source of economic might and power, increased restrictions are imposed on its sharing through intellectual property rights and global trade and technology control regimes. The STP 2003 has also observed that lack of access to scientific knowledge, when S&T advances have profound ethical, legal, and social implications, has created deep concerns in society. The Science and Technology Policy 2003 underlines the decisive and beneficial role of science and technology in advancing the well-being of all sections of our society.

The fourth science policy of the Government of India was structured as 'Science, Technology and Innovation (STI) Policy 2013' with more emphasis on integrating innovation in the S&T ecosystem in the country. It also highlights the relation of the STI system with society, and STI's contribution to social good, economic wealth, and national development. The need for science communication is prioritised for taking the benefits of modern S&T to the people. STI Policy 2013 further states, "the civilisational aspect of science, or scientific temper, needs to be promoted across all sections of the society systematically."

The Indian Government has also prepared a draft Scientific Social Responsibility (SSR) Policy 2019 to develop a stronger connection between science and society while recognising that still much needs to be done taking the scientific knowledge and its benefits to the large society. It states that one way of establishing better science-society linkages is through the translation of scientific knowledge. It proposes to achieve this by institutionalising a sense of social responsibility toward public engagement among scientists and scientific institutions. Science and scientists should share responsibility for addressing the goals and aspirations of the people.

Drawing on the merits of the previous four science policies, the draft 5th Indian science policy 'Science, Technology and Innovation Policy (STIP) 2020' also gives considerable emphasis on interactions among science, society and culture, and in promoting a 'people centric' STI ecosystem in the country. It recognizes the impact of STI on human development, social and economic growth, and nation-building and the contributions of traditional knowledge systems, indigenous technologies, and grassroots innovations in advancing the STI ecosystem. That is, the proposed people-centric STI ecosystem will take the benefits of modern S&T to the people and the traditional knowledge of the people to the modern STI. This attractive policy provision is an indication that science and society should regularly engage and learn from each other.

The above discussion on India's science policies suggests that at least at the government or policy level, science, technology, society, and culture are seen as interrelated and that there is significant emphasis on enhancing science-society interactions and engagement. However, despite these policy provisions, not much public communication of science is happening on the ground. The proposed SSR Policy would be an added gem in further enhancing science-

society engagement, with individual scientists and institutions being mandated to engage with the public.

2.7. Science and the media

Communicating science to the public is challenging as reaching every citizen and translating scientific jargon into people's language is not easy (NASEM, 2017). However, communications through different mass media and social media can help take the message of science to the larger society with higher efficacy and reach in less time. That is why science communication through media (newspapers, magazines, TV, radio, online, etc.), direct interactions, social networks, and other digital/online formats is highlighted (Wellcome Trust, 2001; Peters, 2013; Merino & Navarro, 2019). However, when the changing communication landscape provides new opportunities and avenues to communicate/engage with others, there are new challenges (NASEM, 2017).

After leaving school/college, most adults generally use and primarily rely on different popular media for getting news and views about science (Nelkin, 1995; Wellcome Trust, 2001; Weigold, 2001; Lundy, Ruth, Telg & Irani, 2006; Olson & Kutner, 2008; Besley & Tanner, 2011). Even the science-educated people who are not active in scientific research rely on the popular media/press for news on science. Therefore, these media can be powerful tools for enhancing scientific literacy on a large scale (Gascoigne & Metcalfe, 1997; Treise & Weigold, 2002; Mathews, Kalfoglou & Hudson, 2005).

The journey of science communication through mass media started with science writers who wrote for the popular press (newspapers, magazines) or wrote popular science books (fiction/non-fiction). However, their number was relatively minimal. Knowing that almost all

science is done in English, this number is further smaller for science writers writing in regional and local languages. Furthermore, in newspapers, the number of journalists reporting science has traditionally been minuscule. Even then, science news must complete various stories on other topics for space in print (Weigold, 2001).

The struggle for science to get in print becomes more complicated with the gate-keeping process in newspapers. When most journalists and editors (in newspapers/TV news channels) are from arts and humanities backgrounds, who may find it challenging to understand the technical language of science (scientists), the chances of getting science in print further get thinner. Also, due to various reasons, science stories require relatively more time to develop, and it is also difficult to get appropriate sources for science news in time. These concerns have traditionally kept the science coverage in the popular press or the electronic media (the radio and TV) to a minimum.

Now, it is common to understand that the media give less time/space to science than politics, crime, sports, cinema, etc. Much of the literature on science in the media also suggests that science coverage in the media (in general, and specifically in India) remains low (e.g., Weigold, 2001; Salwi, 2002a; Patairiya, 2002; Patairiya, 2003; Besley & Nisbet, 2013; Dutt & Garg, 2000; Gregory, 2003; Nautiyal, 2010; Kumar, 2013; Peters, 2013; Merino & Navarro, 2019). Kumar (2013) found that the coverage of science and technology in India's leading Hindi and English newspapers was as low as 2% of the total printed area of Hindi and English newspapers studied.

Not only the quantity of science content is less in the media, but there are also other concerns related to the quality of science coverage in the media, including misreporting, misquoting,

factual inaccuracies, wrong attributions, etc. (Gascoigne & Metcalfe, 1997; Wellcome Trust, 2001; Merino & Navarro, 2019). Inadequate coverage of science in the media can potentially limit the public's awareness about science, leading them toward scientific ignorance or illiteracy. Scientific ignorance fails the public to appreciate the benefits of science and may even force them to oppose science or scientific projects (Bubela et al., 2009; Ahteensuu, 2012; Rajput, 2017). Also, events that create controversies are found to attract more news coverage in the media (McCluskey, Kalaitzandonakes & Swinnen, 2016). More coverage of controversies than the scientific content in the media may create distrust about science in public. In the absence of appropriate science communication efforts for bridging the science-society divide, pseudoscience, misinformation, and fake news may become part of everyday public discourse. It would further affect the relationship between science and society and increase public distrust on science (Agre & Leshner, 2010). Such a situation also calls for, among other things, scientists owning responsibility for public communication of science through improving the quality of science coverage in the media.

However, with the increasing literacy rates around the world and the increasing interference and interventions of science in our daily life, the demand for access to scientific information/news is ever-increasing (Fujun & Xiaojun, 2012; HCSTC, 2017; Rajput, 2017a; Fitzpatrick et al., 2020). This increasing demand has inspired some big popular press/media outlets to run some special science features/news segments and recruit science journalists/reporters or assign unique science beats. Nevertheless, this has not increased the science news coverage to a satisfactory level so far (Patarirya, 2002). The local and small press/media outlets, especially in the local and regional languages, cannot afford the luxury of having science beats/reporters. They generally depend upon wire news services or press releases for science news which they need to translate into the local language.

When popular press/media has not successfully disseminated scientific information to the public, specialized science press/media has also emerged. According to Weigold (2001), specialty science magazines and TV channels have successfully taken the message/knowledge of science to the audiences (public). Many science magazines such as *Scientific American, Discover, Popular Science, Science Reporter* have created a great demand among readers who want to read about science. Similarly, TV channels including National Geographic, Discovery, Animal Planet, and Discovery Science have gained immense popularity worldwide, creating an excellent viewership for science-based programmes. Lately, the Government of India is also working on launching a full-fledged 24x7 science channel. DST and Vigyan Prasar are working on this project, and they have already launched a 24x7 IPTV science channel "India Science."

When many in the media believe that the public is not interested in science, Weigold (2001) has suggested that if science is presented in an exciting way to the public, it is not very difficult to attract readers or viewers to the science content in the popular press/media. Different agencies or individuals realized the power of mass media in spreading messages (of science) to the public. Even UNESCO, recognizing its importance, placed science popularization on their list of priorities in 1985 (Spurgeon, 1987). Therefore, mass media are considered powerful tools for popularizing science and bringing changes in public perceptions and behaviours (Abroms & Maibach, 2008; Olson & Kutner, 2008; McCluskey, Kalaitzandonakes & Swinnen, 2016; Dhanashree et al., 2020).

To address the knowledge deficit and to move the public from ignorance to awareness of science, mass media have the potential to multiply a message and take it to a larger audience

for public consumption. Daily coverage of science-related stories in the media can considerably increase the public interest in science, leading to the popularisation of scientific knowledge and scientific advances (Olson & Kutner, 2008). In addition to newspapers, the radio, TV, and general science magazines/books also play a crucial role in popularising science among the masses (Weigold, 2001). With the arrival of digital and new media, the public pays much attention to online sources of science news and views.

Much of the science popularisation activities through the media focus on disseminating science messages and making them popular among different audiences or the general public. Accordingly, it is generally perceived as one-way dissemination of information from the sources (scientists) to the receivers (the public), giving the impression that it is a PR activity of scientific institutions.

2.8. Science communication as an academic discipline

Academically, science communication is a newly emerging multi-disciplinary and inter-disciplinary subject (Trench & Bucchi, 2010; Priest, 2010; Pitrelli, 2010) that is already established as a recognised subject of university teaching and research (Trench, 2012) and is increasingly getting the shape of an academic discipline (Davis, 2010; Trench, 2012; Rajput, 2017). Science communication courses are being taught at undergraduate and postgraduate levels, and related departments/centres are being established at many universities worldwide (Mulder, Longnecker & Davis, 2008; Trench, 2012; Gascoigne et al., 2010; Patairiya, 2016; Rajput, 2017). Many universities and academic institutions around the globe are also offering doctoral research (PhD) programmes in science communication which is an indicator for science communication getting a stronger hold as a university subject of teaching and research (Trench, 2012).

Many of the postgraduate courses in science communication try to develop human resources and capabilities for communicating scientific knowledge and practices to the general public and other specialist and non-specialist audiences. On the other hand, PhD and research programmes try to understand better the nitty-gritty of science communication processes, science-society interactions, and research for improving such communication practices and capabilities.

In addition to being a subject of teaching and research at universities, to make an area an academic discipline, a sizable body of literature in journals, journal articles, and books is also a prerequisite. Over the last three decades, several peer-reviewed research journals on science communication have been established. Some prominent research journals are Science Communication, Public Understanding of Science, Journal of Science Communication, International Journal of Science Education Part B (Communication and Public Engagement), Indian Journal of Science Communication, Science Communicator, Environmental Communication, and Journal of Health Communication. Martin (2016) notes that the number of research papers in this field shows a sharp growth since the 1990s (p.19). Many quality books on different aspects of science communication have been written and made available to readers and learners. Also, the establishment and existence of academic and professional bodies and conferences add to science communication being its own discipline.

The need for formal and informal education or training in science communication has been emphasized to create a trained force to communicate science with the public (Dornan, 1990; Dickson, 2004; Trench, 2012; Rajput, 2017). Recognizing this need for formal training and capacity-building, different universities across the globe have started degree/diploma courses

in the name of science communication or its various names. Trench (2012) traces science communication as a university subject of teaching in several countries in the late 1980s. For example, the Australian National University (ANU) established such a course in 1987. Many more such courses appeared in different countries such as Australia, the United Kingdom, Britain, Spain, Italy, France, Ireland, Netherlands, and Mexico in the next decade of the 1990s. In the following decades, more institutions and countries joined to start science communication courses.

Some of the universities/academic institutions that established science communication degree/diploma courses include: Australian National University, Australia; Imperial College London, UK; Dublin City University, Ireland; International School For Advanced Studies (SISSA), Italy; University College London, UK; Cornell University, USA; University of Campinas, and National Autonomous University of Mexico, Brazil; University of California, USA; Technion – Israel Institute Of Technology, Israel; Louis Pasteur University, France; University of Helsinki, Finland; Free University of Berlin, Germany; Leuven University, Belgium; The Open University, UK; University of Twente, The Netherlands; University of Otago, New Zealand; University of Padova, Italy; University of Aveiro, Portugal; Hokkaido University, Japan; Laurentian University, Ontario, Canada; National University of Singapore; and Korea Advanced Institute of Science and Technology. Starting new masters and doctoral programmes in science communication at academic institutions in different parts of the world is continuing.

India also started such courses in science communication in the early 1990s, but the current situation sounds bleak. In 1982, the Government of India established the National Council for S&T Communication (NCSTC) under the Department of Science and Technology as the top

body to look into the matters related to science communication in the country. One of the significant initiatives of NCSTC was to start training programmes in science communication and courses at different universities by providing necessary guidance and initial budgetary support. Therefore, with the help of NCSTC, several Indian universities started postgraduate degree/diploma courses in science communication/journalism (Rajput, 2008; Patairiya, 2016; Rajput, 2017). Institutions such as Devi Ahilya University, Indore; Lucknow University, Lucknow; Anna University, Chennai; Makhanlal Chaturvedi National University of Journalism & Communication (MCNUJC), Bhopal; and Madurai Kamraj University, Madurai; and National Council for Science Museums, Kolkata in collaboration with BITS, Pilani started Science Communication programmes. Instead of running a full degree course, some universities offered a paper/semester course on science journalism/communication as part of their journalism and mass communication degrees (Patairiya, 2016). However, most of these science communication courses have already been stopped due to one or the other reasons (Rajput, 2017). It suggests that Indian academia has failed to give the due attention science communication as a discipline or as a subject of teaching and research deserves. Therefore, to address the demand for creating trained science communicators in science, technology, engineering, agriculture, and medicine (STEAM) fields, academic institutions should reconsider their position on offering science communication courses.

Further, lacking uniformity about the course name, different institutions/universities named their courses on science communication differently. Initially, different institutions started such courses under different names related to science communication, but now, the term 'Science Communication' is getting more popular as the recognised name of university courses/programmes in the field. Further, science communication programmes at different institutions show variations in the structure and curricula contents, and the need for a

common framework for such university courses was proposed (Mulder, Longnecker & Davis, 2008). Hong and Wehrmann (2010) also found that there was vagueness in the objectives, structures, and contents of the curriculum of science communication programmes they studied. Therefore, more focus and clarity were emphasized while structuring and running science communication courses so that the students become trained and well-equipped science communicators (Hong & Wehrmann, 2010).

Further, some researchers suggest that both practitioners and researchers in science communication should engage more to each other and help each other to further advance science communication as a discipline (Miller, 2008; Davis, 2010). Davis (2010) even suggests that the research and theory of science communication are not aiding much in improving science communication practice and emphasized more research on the practical aspects.

2.9. Policies for science communication

Several countries have adopted policy routes to provide guidelines and mandates for encouraging and advancing science communication through the involvement of different stakeholders. Several others might be working on similar recommendations. Here, some national (science) policies with provisions for science communication or policies specifically for science communication are briefly discussed.

The Royal Society of New Zealand (2016) has prepared *Public engagement guidelines for researchers, scholars and scientists* to support the inclusive engagement of stakeholders in research, scholarship, and science. Based on three guiding principles of Engaged and

informed society, Context and obligations, and Professionalism, transparency and trust, this policy document provides explicit guidelines for scientists on how to engage with the public.

The Government of Thailand (2012), in its National Nanotechnology Policy Framework (2012-2021), has added a strategy for promoting awareness and communication to develop an understanding of nanotechnology. This strategy aims to promote public understanding of nanotechnology on a continuous basis while exploiting different channels and building linkages for raising awareness. Further, Thailand's National Science and Technology Strategy Plan (2004-2013) had a core strategy for raising awareness of science and technology to continuously support the public (National Science Technology and Innovation Policy Office, 2004).

The Republic of South Africa, recognising the importance of public engagement with science, has prepared a 46-page 'Science Engagement Strategy 2015' document through her Department of Science and Technology (SA-DST, 2015). The strategy intends to encourage public engagement leading to an appreciation of S&T and its role in building a knowledge economy and a better life for all. Applicable to all the knowledge fields in South Africa, it aims to foster better, more valuable science engagement. The interesting thing is that they did not stop at preparing the strategy only but went to chart out a 55-page long implementation plan for this strategy (SA-DST, 2017).

The People's Republic of China went one step ahead and enacted a law in 2002 for science popularisation in the name and style of the *Law of the People's Republic of China on Popularization of Science and Technology*. It has several interesting provisions to increase and promote science communication efforts in China. It aims to increase efforts for

popularizing S&T, raising the citizens' scientific and cultural level, and promoting economic and social progress. While communicating S&T knowledge and promoting scientific ideas, the Law emphasises making it easy for the general public to understand, accept and participate in science, and carry forward the scientific spirit.

USA's National and Commercial Space Programs Act that governs NASA has a provision for public engagement as "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof" (NASA, 2010). Further, an amendment to this Act adopted on 21 March 2017 adds a section on Education and Outreach wherein it requires NASA to engage with the public and educate and inspire students to the maximum extent practicable.

The Republic of Columbia has a national public policy on social appropriation of science, technology and innovation (SASTi). This policy recognises scientists as potential science communication (SASTi) actors while also suggesting that they should be provided training in science communication. Nevertheless, it also considers scientists not being aware of their social responsibilities as a limitation in achieving SASTi. (*Thanks to Dr. David Vásquez Muriel of Universidad de los niños EAFIT, Colombia for sharing a gist of this policy in English*)

In Finland, national recommendations for science communication entitled *Bold communication, responsible influence. Science communication recommendations* were prepared by the Committee for Public Information (2018). This document has many provisions for increasing science communication with the public, integrating it as an essential part of research while emphasising that every researcher is responsible for communicating their research to the public.

In Germany, Wissenschaft im Dialog and the Bundesverband Hochschulkommunikation developed *Guidelines for good science PR* in 2016. Recognising the impact of science on social and individual life, this document provides necessary guidelines to R&D institutions on improving their science communication with the public through science PR.

In the UK, a science communication and engagement report submitted to the House of Commons by the Science and Technology Committee highlighted the government's primary responsibility for fostering and facilitating science engagement in policymaking (HCSTC, 2017). Possibly recognizing that many controversies surrounding science are generally flared by media mishandling, this report suggests the UK Government to "ensure that a robust redress mechanism is provided for when science is misreported" (HCSTC, 2017).

Some funding agencies are also asking projects to include science communication as part of the proposed research. For example, in their new guidelines for funding proposals Proposal and award policies and procedures guide, the USA's National Science Foundation requires 'broader impacts' as a mandatory field under the project description (NSF, 2020). Valuing scientific knowledge and its advancement for societal benefits, these guidelines require explanation on projects' contribution in increasing public understanding of S&T and in improving social well-being.

As discussed above, it is evident that science communication is getting considerable attention from policymakers and national governments. This attention only suggests that science communication is an important area of work that needs policy interventions for better results.

In India, science communication gets significant attention at the policy level. India is possibly the only country that has an implicit provision for science communication in her constitution. 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)). Several science policy documents emphasise the need for science popularisation. India's first science policy document (Scientific Policy Resolution, 1958) was prepared soon after independence to provide a direction to the scientific community and the larger society for proper utilisation of scientific advances to achieve social, developmental, and national goals. It laid significant emphasis on spreading the message of science to the public as a priority area. The Scientific Policy Resolution (SPR) 1958 encourages "individual initiative for the acquisition and dissemination of [scientific] knowledge" and to take the benefits of scientific knowledge to the people of the country. The 'individual initiative for dissemination of knowledge' suggests that scientists who have scientific knowledge must disseminate it to the larger society through their individual initiatives. Under the notion of individual initiative for acquiring scientific knowledge, it also instructs the common citizens to do their best in learning about scientific knowledge for their own benefit.

The second science policy of India (Technology Policy Statement 1983) also aims to ensure that our available natural endowments, especially human resources, are optimally utilised for a continuing increase in the well-being of all sections of our people. It implies the optimal use of scientific information resources for the public – an indication for science communication. The subsequent science policies have also reiterated the need for ensuring the message of science reaches every citizen of India. The very first objective of the third science policy 'Science and Technology Policy 2003' stresses the need for taking the message of science to

every citizen, promoting scientific temper, and ensuring people's participation in S&T and its application for human welfare.

The fourth policy, 'Science Technology and Innovation Policy 2013,' also recognizes the importance of public understanding of science, taking the benefits of S&T to the people, and promoting scientific temper by using effective science communication methods.

The recently proposed two draft science policies of the Government of India – the Scientific Social Responsibility (SSR) Policy 2019 and the Science, Technology and Innovation Policy (STIP) 2020 – lay even more emphasis on promoting science communication and public engagement in the country.

The SSR Policy suggests making scientific social responsibility a mandatory activity for scientific institutions and individual scientists and suggests several interventions for enhancing engagement between science and society (Department of S&T, 2019). Every S&T institution will be required to prepare its SSR activities as per its mandate. Every scientist would be expected to spend ten person-days for public engagement as social responsibility. It also suggests incentivizing individual and institutional SSR activities through monetary support. It proposes to give due credit to PE activities in individual scientist's annual appraisals and promotions.

The proposed STIP 2020 gives even greater emphasis by introducing a whole chapter on science communication and public engagement (Department of S&T, 2020). The encouraging provisions contained in the STIP 2020 are expected to accelerate and liberate India's potential for science communication and public engagement. Recognising the knowledge

deficit and lack of public engagement in science, STIP 2020 hopes that science communication has the potential to bring scientists and the public together. While giving needed importance to increasing communication or dialogue between science and society, scientists' active involvement in science communication activities through upstream engagement and a citizen-centric approach is also emphasised (Department of S&T, 2020). Another important aspect of this proposed policy is that it seems to recognise science communication as an area of professional and academic expertise when it underlines the "need for creating awareness and recognition for science communication as a field of practice." The proposed policy is expected to promote research in science communication, training, and capacity-building of scientists and science communicators, and inclusion of science communication skills at different levels of science education. Like SSR Policy, it also proposes addressing the important concern of giving due career benefits to scientists and science communicators for their PE activities.

STIP 2020 further intends to mainstream science communication in the Indian S&T ecosystem through various initiatives such as setting up science communication wings at every public-funded S&T institution, creating a national movement for science popularisation, building infrastructure and more avenues for public engagement, and creating science media centres for improving science visibility in the media. The demand for establishing science communication departments at every public-funded R&D institution has been pending since it was first emphatically put forward by D.M. Salwi in his famous book *Science in India Media* (Salwi, 2002a).

On the other hand, there are concerns that policies forcing scientists to engage more with the public may impact scientists' research performance and attitudes toward public engagement.

Some studies (Larsen et al., 2011; Daguang, 2008) even noted that external pressures compelling scientists to engage against their will could negatively impact scientists. Therefore, it would be a better idea if scientists willingly take up the responsibility to engage (Loroño-Leturiondo and Davies, 2018; Larsen et al., 2011). However, seeing positive effects on both the public and scientists themselves, Varner (2014) suggests that science communication should be made personally meaningful and relevant to scientists and the public for better results.

Notwithstanding any criticism, if these two proposed draft science policies are correctly implemented, these should bring a paradigm shift in the science communication landscape in India. These policies are also expected to provide more robust support in establishing science communication as an academic discipline or a specialised field of academic and professional expertise. However, it would always be advisable to support such policy initiatives through strong empirical evidence. The current study is an attempt in this direction to provide some empirical evidence on science communication by scientists. Such evidence would only inform policymakers to come up with more effective and better policies.

2.10. Science communication in India

Despite constitutional and policy provisions, science communication through various media has remained a much-neglected area in India until recently (Salwi, 2002a: p. ix). Nevertheless, several governments, private entities, and NGOs have been involved in promoting science among the masses. According to a recent directory compiled by the Department of Science and Technology, India is home to 6862 R&D institutions (DST-NSTMIS, 2018). Still, only a few organisations such as NSCTC, Vigyan Prasar, NCSM, and CSIR-NISCAIR (now, CSIR-National Institute of Science Communication and Policy

Research) actively and exclusively work for science communication or popularisation in the country. Here, some prominent activities, initiatives and programmes are briefly touched to provide a flavour of how science communication is taking shape in India.

At the central governmental level, the National Council for S&T Communication (NCSTC) under the Union Department of S&T (DST) was established in 1982 as the apex body in the country for formulating, executing, financing, supporting and catalysing various science communication activities. NCSTC has played an instrumental role in initiating various science communication and popularisation programmes, including National Children's Science Congress, and Teachers' Science Congress. It also supported the Indian Journal of Science Communication (IJSC) and the famous Hindi fortnightly newspaper '*Vaigyanik Drishtikon*' published from Jaipur. A national-level annual science communication conference was also initiated to promote sharing of best practices in science communication research and practice while encouraging networking, cooperation and collaborations. Another crucial area where NCSTC contributed significantly was the inception of various degree/diploma courses in science communication/journalism at different universities and other academic institutions (Rajput, 2008; Patairiya, 2016; Rajput, 2017). Acting as a national funding body for science communication projects, NCSTC supported many science popularisation initiatives financially, including production of popular content in print material, radio and video programmes, workshop on science activities, and science communication skills workshops. NCSTC has also constituted several awards for outstanding contributions in science communication through different formats/media. To promote science in society, a national science day is observed on 28 February, celebrating the historic discovery of the Raman effect. The Science Express (a science exhibition on the train) was another effort to attract and engage people to science.

Vigyan Prasar is a central autonomous body under DST that serves the nation through various science popularisation activities. Its activities include producing popular books, radio and TV programmes, popular magazines such Dream 2047, Vipnet News (now Vipnet Curiosity), communication through ham radio, science films, and science-based activity kits. It also runs a national annual science film festival to promote and encourage science filmmaking in India. To promote science at the grassroots level, Vigyan Prasar collaborated with the All India Radio (AIR) and scriptwriters to produce many science-based radio serials, which were broadcast in different Indian languages across the country through AIR stations. It also produced science-based weekly TV bulletins (in English and Hindi) for broadcasting through Doordarshan, RSTV, and LSTV. Vigyan Prasar is now leading the country's first 24x7 IPTV science channel 'India Science'. To provide ready-to-use S&T news and features to various media outlets, it recently started India Science Wire as a science news agency providing free content in Hindi and English. Vigyan Prasar's activities have traditionally been in Hindi and English, but now it is slowly expanding its scope to other Indian languages. It is also coordinating DST's ambitious programme AWSAR (Augmenting Writing Skills for Articulating Research), where doctoral and post-doctoral researchers in science are encouraged to write a popular science story about their research for the general public, and the selected stories are given attractive prizes.

The National Council of Science Museums (NCSM) is another body under the Union Ministry of Culture. It runs and manages a large network of science museums, science cities and science centres around the country. It is involved in various activity-based and engagement-based science popularisation events. The various museums and centres under NCSM see an annual footfall in millions. As science museums and centres are not available

in every city and village, NCSM initiated mobile science exhibitions through modified buses.

CSIR-National Institute of Science Communication and Information Resources (NISCAIR) is another important organisation that produces several science communication products. In addition to publishing different research journals, it brings out popular science magazines such Science Reporter, *Vigyan Pragati*, and *Science ki Duniya*. Recently, NISCAIR started masters and doctoral programmes in science communication to create trained science communicators and further science communication research. NISCAIR was recently merged with CSIR-NISTADS and renamed as CSIR-National Institute of Science Communication and Policy Research (NIScPR).

Some other institutions are also contributing to the popularisation of science. For example, the National Research Development Corporation (NRDC) also brings out two popular science magazines: *Awishkar* (Hindi) and Invention Intelligence (English). Similarly, several other popular science magazines have been brought out by different government and non-government entities. To name some are: Down to Earth by CSE, Everyman's Science by ISCA, Vaigyanik by BARC, *Kheti* and India Farming by ICAR, and Science India by Vijnana Bharati.

Several non-government entities such as NCSTC-Network, Indian Science Communiction Society (ISCOS), and Indian Science Writers Association (ISWA) are also involved in science communication activities. Doordarshan and All India Radio also run different science, technology and agriculture based programmes. Many state level NGOs are active in science popularisation in regional languages. Vijnana Bharati – a volunteer organisation – is

also very active in science communication activities. Its recent and prominent initiatives include TechforSeva conferences, Bharatiya Vigyan Sammelan (BVS), and the India International Science Festival (IISF) that is executed with the support of government agencies. The Indian Science Congress organised annually by the Indian Science Congress Association (ISCA) includes a mega science expo called Pride of India, which is a huge success in attracting visitors and showcasing them Indian R&D advances and achievements in an interactive way. ICAR's Krishi Vigyan Kendra (KVKs) serve as centres of agricultural knowledge sharing among agriculture scientists and farmers. The National Centre for Science Communicators (NCSC), Mumbai is also contributing considerably to this area.

Vigyan Jathas was an exciting initiative where science popularisation activities were carried through science journeys by a small team of scientists, artists and communicators from village to village and conveying the message of science at the grassroots level (Rautela & Chowdhury, 2016).

It is understood that most of these efforts in science communication in India follow the deficit approach. However, some significant efforts through dialogue and participatory science communication in the form of exhibitions, expos, science museums/centres, lab visits, etc. are available at the institutional and government level.

Nautiyal (2008), while presenting an overview of various science communication and popularisation activities in India, suggests that there is considerable progress in science communication in the country. Patairiya (2016) highlights the various achievements, initiatives, and institutional and individual efforts made toward advancing science communication in the country and suggests that a mix of traditional and modern tools of

communication and public engagement would be desirable to reach the vast population with a large diversity of social, cultural and lingual values. Despite many appreciable efforts being made, much still needs to be done to bridge the wide gap between science and society (Nautiyal, 2008; Patairiya, 2016; Rautela & Chowdhury, 2016). Several interesting and useful interventions were suggested earlier by Salwi (2002a) to fill this gap. Also, an analysis of demand and supply of different science communication products suggests gaps in supply to meet the demands (Patairiya, 2002).

In the complex and diverse socio-cultural, lingual and economic milieus coupled with variable literacy levels, communicating science with the public has always been a challenge in India. There is also a lack of scientists and science communicators who are trained and skilled in communicating science in simple language, especially in the local Indian languages. Presenting science to the public in local languages has always been emphasised but less realised. If such science outreach and dissemination efforts do not go beyond the English language, it would be difficult to reach the masses who speak Indian languages, especially the lower strata of society with no English language access. If such a large proportion of the Indian population remains unaware of the scientific advances happening in the country and abroad, it would undoubtedly impair our developmental agenda and the aspiration of becoming a knowledge economy.

Many initiatives are doing well but are mainly executed in the one-way broadcast 'deficit' mode. All the many efforts done so far appear relatively small before our population of about 1.35 billion. Science communication efforts need to be intensified and magnified, keeping in view the large population size. More avenues for public engagement and participation in science are needed.

2.11. Scientists' importance of science communication

Several studies on scientists' perceptions and attitudes toward science communication in other countries (including America, UK, Scotland, England, Germany, Taiwan, Great Britain, Italy and Mexico) have highlighted that many scientists believe communicating science with the public is an important activity where scientists should regularly contribute and participate actively (Wellcome Trust, 2001; Mathews, Kalfoglou & Hudson, 2005; Pitrelli, Brunelli & Murellia, 2006; Royal Society, 2006; Thompson et al., 2009; Searle, 2011; Dang & Russo, 2015; Grand, Davies, Holliman & Adams, 2015; Lo, 2015; Guerrero, 2016; Merino & Navarro, 2019; Rose, Markowitz & Brossard, 2020; Valinciute, 2020). Bond & Paterson (2005) also reported that engaging and interacting with the public or civil communities, both in principle and practice, was considered important by many researchers in Scotland and England.

Even when there are challenges in engaging with the public, many scientists still believe in the importance of science outreach and engagement activities (McCann, Cramer & Taylor, 2015). Thompson et al. (2009) revealed that science communication was seen as an important activity and most health researchers perceived potential benefits of engaging with the public. While highlighting the importance of public engagement, astronomers from 31 different countries even suggested that researchers should invest more time in public outreach activities (Dang & Russo, 2015). Some studies suggest that senior scientists intend to be more active or interested in public science communication activities than their junior counterparts (Royal Society, 2006).

These studies investigating scientists working in different academic disciplines and at different types of institutions (employers) across countries suggest that scientists are largely aware of the importance of science communication with the public. Even this sense of the importance of science communication is almost the same across demographic variables such as age and gender (Besley, Oh & Nisbet, 2012). It is an encouraging thing for advancing science communication because, without scientists' active involvement, such efforts would not succeed as intended. Without knowing whether science communication is a priority for scientists, asking them to contribute does not make much sense. However, no such significant studies exploring what scientists think about science communication and its importance are available in the Indian context.

2.12. Scientists' sense of moral duty, role, and responsibility

Several studies (e.g., Shugart and Raceneillo, 2015; Loroño-Leturiondo and Davies, 2018; Varner, 2014) have noted that scientists' active involvement in public communication of science is not only beneficial to the publics, but also to scientists themselves, especially in democracies where scientists need political and public support to execute their R&D projects. However, if scientists fail to communicate the importance of their research and its societal/ethical implications, there are chances that they may lose funding opportunities or the necessary approvals to execute their projects.

Any miscommunication or no communication at all or misadventures on the part of scientists can potentially weaken science-society relations leading to public distrust on science (Agre and Leshner, 2010). Such lack of trust may further translate into public opposition to science and even into anti-science movements. Further, Agre and Leshner (2010) noted that

miscommunications about science not only question the integrity and credibility of the concerned scientists/organisations but the entire scientific community.

Such a situation requires scientists to take up the responsibility to create and share authentic and reliable communications for consumption by the larger public. If they do not take this responsibility, then vested interests and lobbyists may take over the public discourse on science (Shugart and Raceneillo, 2015). The non-involvement of scientists may give these people a free hand to run their own propaganda and misinformation campaigns to achieve their goals at the costs of tarnishing the image of science and scientists (Agre and Leshner, 2010).

If there are no checks and balances in place or nobody takes responsibility for better informing the public, misinformation, false claims, and fake news on popular media and social media would continue to influence the larger society. Unrestricted flow of such unscientific claims may promote pseudoscience as the mainstream narratives in society, which would be detrimental for science-society relations while doing a disservice to achieving a rational and scientifically thinking society. Therefore, pulling scientists to contribute in this direction requires a systematic understanding of whether scientists believe they have any role, duty or responsibility for science communication.

Interestingly, many scientists in different countries (e.g., USA, UK, Australia, Spain, South Africa, Mexico, Switzerland, Basque Country) have already reported that they have a sense of moral duty or responsibility toward public engagement (Wellcome Trust, 2001; Conradie, 2004; Royal Society, 2006; Lundy et al., 2006; Searle, 2011; Roten, 2011; AAAS, 2015; Hamlyn et al., 2015; Lorono-Leturiondo & Davies, 2018; Farahi et al., 2019; Llorente et al.,

2019; Merino & Navarro, 2019). In other words, scientists in these countries believe that they have a responsibility or duty to help people understand their research and its social and ethical implications.

However, Davies (2008) and Varner (2014) have observed that scientists are more inclined to approach their responsibility through the one-way deficit mode of communication. Therefore, going beyond the deficit and making science communication more exciting, scientists are required to actively participate in public debates on science (Pew Research Center, 2015).

Initially, scientists were reluctant to accept that engaging with the public was part of their job (Royal Society, 2006). But, nowadays, many scientists believe that communicating science with the public is part of a scientist's professional responsibilities (Searle, 2011; Peters, 2013; Farahi et al., 2019; Merino & Navarro, 2019). However, it still remains unclear whether many S&T institutions officially include science communication with the public as part of a scientist's job and assigned roles and responsibilities, or it is just scientists' personal assumption that it is part of their job.

2.13. Science Communication by institutions

R&D Institutions generally do not give much importance to science communication and outreach activities. Institutional efforts toward science communication are not seen as sufficient (Guerrero, 2016). Two large scale multi-institutional studies (mostly involving European and western countries) have observed that most research institutions are not serious about science communication as an institutional priority and lacked a culture of public engagement (Neresini & Bucchi, 2011; Entradas et al., 2020). These studies suggest that science communication, being a low key area at the institutional level, is yet to become a

fully instituted activity that is well recognised and valued. Entradas et al. (2020) also suggest that if there is an institutional mandate to communicate science with the general public, more scientists are expected to contribute and engage in science communication activities.

However, several other studies (e.g., Gascoigne & Metcalfe, 1997; Wellcome Trust, 2001; Gething, 2003; Andrews et al., 2005; Lunsford, Church & Zimmerman, 2006; Royal Society, 2006; Poliakoff & Webb, 2007; Peters et al., 2008; Edge et al., 2011; Searle, 2011) have noted that institutional support, recognition and sense of priority are essential for ensuring science communication efforts, specifically through the involvement of scientists. In the absence of such institutional priority, scientists who are active in public engagement largely do so in their personal capacity or out of their personal interest.

Lack of institutional support, recognition and incentives for scientists' active participation in science communication activities has been frequently highlighted as one of the major obstacles in the way of public engagement by scientists (e.g., Royal Society, 2006; Poliakoff & Webb, 2007; Kreimer, Levin & Jensen, 2011; Searle, 2011; Torres-Albero et al., 2011; Agnella et al., 2012; Shugart & Racaniello, 2015; Watermeyer, 2015; Valinciute, 2020). Institutional level support is necessary to encourage scientists' participation in science communication and public engagement activities (Lunsford, Church & Zimmerman, 2006).

2.14. Science communication by scientists

The area of science communication is witnessing considerable interest from people from different walks of life. In the whole enterprise of science communication, scientists are expected to play an essential role as they are the creators of scientific knowledge. With science communication and public engagement catching attention, there is an ever-increasing

demand for the 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.*, Royal Society, 1985; Wellcome Trust, 2001; Royal Society, 2006; Nisbet & Scheufele, 2009; Agre & Leshner, 2010; Nautiyal, 2010; Shugart and Racaniello, 2015; Dudo & Besley, 2016).

In this context, the Bodmer Report (Royal Society, 1985) says that "scientists must learn to communicate better with all segments of the public, especially the media" (p.24). It goes on further to say that "our most direct and urgent message must be to the scientists themselves: learn to communicate with the public, be willing to do so, indeed consider it your duty to do so" (p.36) and that "it is clearly a part of each scientist's professional responsibility to promote the public understanding of science" (p.24).

In a large survey-based study of UK scientists, the Royal Society (2006a) found that "the communication of research results can have significant impact on members of the public, leading to changes in their views, attitudes and behaviour" (p.6). This report also highlighted two main responsibilities of scientists or researchers towards the public: (1) to accurately assess the potential implications of research for the public, and (2) to communicate timely and appropriately such things to the public (Royal Society, 2006a, p.5). The report further recommends that these two responsibilities should be assimilated within the culture of science or research.

Despite such recommendations for active engagement, many scientists have generally been critical about the involvement of research scientists in public engagement or media events. They generally perceive these activities as a diversion from their primary role of doing

science. Many people from the media and the scientific community believe that scientists are generally shy of media/press and are not very good communicators (e.g., as noted by Royal Society, 1985; Shugart and Raceneillo, 2015). Scientists are also seen admitting that they find it difficult to talk to the public/press in the language these people can understand. The stigmatic 'Sagan effect' associated with scientists' public engagement is also seen to impact scientists' reputation, often leading to their isolation in scientific circles (Echlund et al., 2012; Shugart and Raceneillo, 2015).

However, since the 'public understanding of science' movement started in the mid-1980s, a shift in the perceptions of different stakeholders in science or science communication has slowly started. Along with other promoters of science communication, some scientists are also favouring enhanced science-society interactions, and some are also willing to contribute for the same actively. Different studies suggest that communicating science to the public is one of scientists' important responsibilities or duties, especially when the public money funds science (e.g., Martín-Sempere et al., 2008). These authors also argue that scientists should not only train themselves in doing research but also in communicating it to the public. Different scholars of science communication have placed high importance on the active role of scientists in science communication.

Despite such limitations, many scientists taking part in science communication activities – however, the frequency of their engagement being low or occasional (say, at least once in a year) – has been confirmed by several studies in different countries: UK (Royal Society, 2006; Hamlyn et al., 2015), Denmark (Nielsen, Kjaer, & Dahlgaard, 2007), Argentina (Kreimer, Levin & Jensen, 2011), USA (Sturzenegger-Varvayanis et al., 2008; AAAS, 2015),

Mexico (Guerrero, 2016; Merino & Navarro, 2019), Philippines (Navarro & McKinnon, 2020), and Lithuania (Valinciute, 2020).

Some studies have noted that senior scientists were relatively more active than junior researchers (e.g., Royal Society, 2006, Bauer & Jensen, 2011; Searle, 2011). Boltanski & Maldidier (1970) even noted an increase in public engagement activities as a scientist climbs the institutional hierarchy (as quoted by Bauer and Jensen, 2011). Some other studies (Kreimer et al., 2011; Jensen, 2011) have also found that as scientists move on to the higher levels of a scientific career, they become more active in science communication. Scientists having more experience and confidence in their communication skills were relatively more inclined to engage with the public than junior researchers who are not sure about their communication capabilities (Wellcome Trust, 2001; Royal Society, 2006; Joubert, 2018). Previous experience and behaviours also affect scientists' further participation (Paliokaff & Webb, 2007).

Amid many calls for scientists' engagement in science communication activities, little was known on what scientists themselves think about science communication and their involvement. In this context, 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.*, Wellcome Trust, 2001; Royal Society, 2006; Nielsen, Kjaer & Dahlgaard, 2007; Davies, 2008; Martin-Sempere, Garzon-Garcia & Rey-Rocha, 2008; Kreimer, Levin & Jensen, 2011; Ecklund, James & Lincoln, 2012; Besley & Nisbet, 2013; Guerrero, 2016; Loroño-Leturiondo & Davies, 2018; Merino & Navarro, 2019; Ho, Looi & Goh, 2020; Valinciute, 2020). However, such studies exploring views of

scientists on science communication and their public engagement are rare in the Indian subcontinent, specifically in India.

2.15. Impact of science communication on scientists' careers

Many scientists do not see any personal or career benefits from their engagement in science communication activities (Jensen, Rouquier, Kreimer & Croissant, 2008; Poliakoff & Webb, 2007; Shanley & López, 2009; Jensen, 2011; Agnella et al., 2012). On the contrary, some report the negative impact of public engagement on scientists' careers or professional reputations (Porter et al., 2012; Watermeyer, 2015). However, scientists were quick to suggest that they would be willing to contribute if their public engagement has career benefits (Royal Society, 2006; Dudo et al., 2014).

Many scientists claim that science communication with the public is not regarded well in the scientific community or is often linked to the stigmatic 'Sagan effect' resulting in repercussions for scientists' careers (Royal Society, 2006; Shugart & Racaniello, 2015; Ecklund, James & Lincoln, 2012; Merino & Navarro, 2018; Rose, Markowitz & Brossard, 2020). However, we have no studies explaining how Indian scientists see the relationship between their public engagement and career advancement.

2.16. Major factors affecting science communication by scientists

Several barriers and impediments may mar science communication by scientists. After extensively reviewing much of the literature on factors affecting scientists' active participation in public engagement activities (e.g., Boltanski & Maldidier, 1970; DiBella, Ferri & Padderud, 1991; Gascoigne & Metcalfe, 1997; Pearson, Pringle & Thomas, 1997; Holland, 1999; Wellcome Trust, 2001; Gething, 2003; Conradie, 2004; Andrews et al., 2005;

Lundy et al., 2006; Lunsford, Church & Zimmerman, 2006; Royal Society, 2006; Nielsen, Kjaer, & Dahlgaard, 2007; Poliakoff & Webb, 2007; Davies, 2008; Jensen, Rouquier, Kreimer & Croissant, 2008; Martin-Sempere, Garzon-Garcia & Rey-Rocha, 2008; Peters et al., 2008; Sturzenegger-Varvayanis et al., 2008; Burchell, Franklin & Holden, 2009; Dunwoody, Brossard & Dudo, 2009: Holliman & Jensen, 2009; Shanley & Lopez, 2009; Claassen, 2011; Bauer & Jensen, 2011; Edge et al., 2011; Jensen, 2011; Kreimer, Levin & Jensen, 2011; Neresini & Bucchi, 2011; Roten, 2011; Searle, 2011; Agnella et al., 2012; Ecklund, James & Lincoln, 2012; Porter et al., 2012; Dudo, 2013; Dudo et al., 2014; Jia & Liu, 2014; Varner, 2014; AAAS, 2015; Hamlyn et al., 2015; Pew Research Center, 2015; Shugart & Racaniello, 2015; Watermeyer, 2015; Zhang, 2015; Guerrero, 2016; Besley et al., 2018; Dudo et al., 2018; Joubert, 2018; Lorono-Leturiondo & Davies, 2018; Yuan, Besley & Dudo, 2018; Farahi et al., 2019; Llorente et al., 2019; Merino & Navarro, 2019; Entradas et al., 2020; Ho, Looni & Goh, 2020; Navarro & McKinnon, 2020; Markowitz & Brossard, 2020; Valinciute, 2020), following potential factors and barriers impacting science communication by scientists are identified:

- Lack of time
- Lack of institutional support/encouragement
- Lack of funding
- Lack of communication skills
- No incentives/rewards and recognition
- Deviation from research
- Impact on career
- Difficulty in constructing messages relevant for the public
- Science communication is not part of the duty

- Research is too complex for the public to understand
- Science communication not regarded well – Sagan Effect
- Academic colleagues are not active or supportive
- No personal benefits
- No interest in such activities
- Lack of comfort in such activities
- Past engagement and experience
- Personal enjoyment and satisfaction

These studies highlight that poor communication skills, lack of time, lack of institutional support and encouragement, lack of incentives/rewards, deviation from research, negative impact on careers or no career benefits, lack of funding, and other factors as listed above keep most scientists away from engaging in science communication activities. As noted in several of the studies mentioned above, many scientists believe that not having the requisite communication, media and public speaking skills is a significant hindrance in their participation in public engagement (PE) activities. However, some recent studies suggest a change in scientists' perceptions about the lack of communication skills not being a potential factor for their communication activities (Valinciute, 2020). To increase scientists' involvement in PE activities, several of these studies suggest that government and institutional agencies should do the needful to address the factors and barriers identified as above.

Some of the above listed potential factors affecting scientists' active involvement in science communication are briefly discussed below. For example, the time constraint is a big hindrance for many scientists to engage in science popularisation activities actively

(Gascoigne & Metcalfe, 1997; Andrews et al., 2005; Poliakoff & Webb, 2007; Ho, Looi and Goh, 2020).

Lack of incentives/rewards, lack of institutional support, deviation from doing research, lack of funding, lack of public engagement opportunities, no personal benefit, no effect on advancing careers, difficulty in crafting messages for the non-scientist audiences, etc. are the potential factors limiting public engagement by scientists (Gascoigne & Metcalfe, 1997; Andrews et al., 2005; Poliakoff & Webb, 2007; Jensen et al., 2008; Kim & Fortner, 2008; Martin-Sempere, Garzon-Garcia & Rey-Rocha, 2008; Shanley & Lopez, 2009; Valinciute, 2020).

Scientists with no previous exposure to public engagement generally face difficulty in connecting well with the public. It also suggests that insufficient communication efficacy and experience are other impediments in public engagement (Andrews et al., 2005; Ecklund, James & Lincoln, 2012; Shugart and Racaniello, 2015; Yuan et al., 2017). Also, scientists' inability to talk beyond scientific jargon is a deterrent for the public to connect with science (Sharon & Baram-Tsabari, 2014; Bullock et al., 2019; Shulman et al., 2020; Smith & Merkle, 2021).

How our colleagues and friends do certain things motivates us to do the same. Several studies indicate that many scientists do not perceive that their colleagues regarded science communication as an essential activity or were active in such activities (Royal Society, 2006; Dudo et al., 2018; Rose, Markowitz & Brossard, 2020). Contrary to these findings, another study found that many US scientists believed their academic colleagues were active in public

engagement (Sturzenegger-Varvayanis et al., 2008). However, such understanding is lacking in the Indian context.

Another potential barrier to scientists' frequent public engagement is, assuming the public being ignorant of scientific advances, that the general public cannot understand their complex research (Kreimer, Levin & Jensen, 2011; Valinciute, 2020). Some studies provide evidence to the contrary also (Sturzenegger-Varvayanis et al., 2008). However, scientific topics indeed appear complex for many people, so scientists' active involvement is necessary to explain their science to the public audiences and help them make informed decisions in their lives (Shugart & Racaniello, 2015).

Even when there are no institutional compulsions to engage, many scientists may do so out of personal interest or passion. Personal attributes such as enjoyment and confidence in communicating science play an important role in influencing scientists' decisions to engage or not. For many scientists, personal enjoyment drives their involvement in science communication activities (Pearson, Pringle & Thomas, 1997; Royal Society, 2006; Martin-Sempere, Garzon-Garcia & Rey-Rocha, 2008; Sturzenegger-Varvayanis et al., 2008; Dunwoody, Brossard & Dudo, 2009; Holliman & Jensen, 2009; Searle, 2011; Dudo, 2012; Dudo et al., 2018; Ho, Looi & Goh, 2020). Several of these studies have also shown that scientists positively perceived their ability to communicate science with the public.

Past behaviour or experience is another factor deciding scientists' intentions to engage in the future (Poliakoff & Webb, 2007). It is observed that bad experience in public engagement or media interactions keeps many scientists away from such engagements. However, some

recent studies suggest scientists having positive experiences in engaging with the public/media (Guerrero, 2016; Dudo et al., 2018; Ho, Looi & Goh, 2020).

Willingness to engage in science communication activities is another potential factor that decides the actual participation. Many studies indicate that most scientists expressed their willingness to engage with the public or media (DiBella, Ferri & Padderud, 1991; Poliakoff & Webb, 2007; Zhang, 2015; Besley et al., 2018; Merino & Navarro, 2019). Even being willing to engage, many scientists are not very active public communicators (Jia & Liu, 2014; Zhang, 2015). However, despite several impediments and barriers in the ways of scientists' public engagement, it is an encouraging observation that many scientists investigated across country lines expressed their willingness to engage in or spend more time for science communication in the future (Royal Society, 2006; Martin-Sempere, Garzon-Garcia & Rey-Rocha, 2008; Casini & Neresini, 2012; Allgaier, Dunwoody, Brossard, Lo & Peters, 2013; Dudo et al., 2018).

Possibly being concerned about the above-discussed factors and barriers, many scientists in several studies conducted in countries other than India suggested that if appropriate provisions are made for incentives, rewards, encouragement, recognition, funding, training, policy guidelines, career benefits, making science communication explicit part of the job, and implementing other suggested interventions, then more scientists will get encouraged to engage frequently with the public (Gascoigne and Metcalfe, 1997; Andrews et al., 2005; Royal Society, 2006; Yuan et al., 2017; Farahi et al., 2019; Ho, Looi and Goh, 2020; Rose, Markowitz and Brossard, 2020).

Interestingly, even in the absence of the above-suggested interventions, 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 (Royal Society, 2006; Hamlyn et al., 2015; Wellcome Trust, 2001; Farahi et al., 2019; Llorente et al., 2019; Conradie, 2004; Searle, 2011; AAAS, 2015; Roten, 2011; Merino and Navarro, 2019).

However, no significant studies in India are known to have explored these aspects related to scientists' involvement in science communication with the public. It necessitates systematic exploration of different factors and barriers impacting science communication by Indian scientists, and the possible interventions scientists themselves would improve their public engagement.

2.17. Scientists' interactions with the public/media

When it comes to engaging with the public through different ways of public communication, most scientists generally preferred face-to-face interactions to mediated modes of communication (Royal Society, 2006; Nielsen, Kjaer, & Dahlgaard, 2007; Kreimer, Levin & Jensen, 2011; Besley, Oh & Nisbet, 2012; Dudo et al., 2014; Jia & Liu, 2014; AAAS, 2015; Hamlyn et al., 2015; Dudo et al., 2018; Merino & Navarro, 2019). Also, it is noted that when many scientists have given interviews to journalists (Peters et al., 2008), their highest frequency of public engagement is through face-to-face interactions (Dudo et al., 2018).

'Lack of formal training in communication/media skills' and 'lack of interest in engaging with non-expert groups' are usually cited as reasons for scientists' no public engagement or for their poor performance. Often, institutional policies for media interactions also discourage scientists from engaging with the media (Salwi, 2002a). Misquoting, misreporting,

misrepresentations, misinformation, sensationalisation and distortion of facts by reporters/journalists (as noted earlier in this chapter) are also seen as demotivating factors for less involvement of scientists in science communication activities, especially through the media/press. Most scientists considered lack of control over the communication process is one of the main problems in dealing with the media (Peters, 2013).

Many times, when media coverage of science creates controversies (Bell, 1994; Ransohoff & Ransohoff, 2001; Weigold, 2001; Rinaldi, 2012), many scientists may refuse to engage with journalists to avoid being dragged into such controversies unnecessarily. However, some scientists get attracted to jump in for clarifications in the interest of the public. Scientists have been observed to be concerned about providing correct scientific information to the public so that they can be benefited from science in their daily lives. Peters (2013) has also suggested that many scientists see their interactions with the media as part of the modern scientist's role, not just their moral sense of responsibility but also as part of their professional life. He also observed that the new generation of scientists growing up in the interactive online media might be better conditioned to engage with the media to communicate science to the public, helping to narrow the communication gap between science and society. However, while pointing out the incompatibilities between the professional cultures of scientists and journalists, Peters (2013) also cautioned that scientific communities generally discourage scientists from communicating with the media as this can potentially damage their academic reputation.

2.18. Training in science communication

Scientists are generally seen as poor communicators, at least for non-scientist audiences (Hartz & Chappel, 1997; Weigold, 2001; Olson, 2009). Lack of confidence and ability in

communication skills are often seen as a potential hindrance in scientists' active participation in public engagement activities (Holland, 1999; Hoffman, 2016).

Not having any formal training in communication and media skills, many scientists expressed willingness for improving their skills (Gascoigne & Metcalfe, 1997; Lundy, Ruth, Telg & Irani, 2006; Dudo, 2013; Guerrero, 2016; Merino & Navarro, 2018). Further, it is noted that scientists with formal training are more likely to feel competent and engage more in science communication activities (Dudo, 2013; Ho, Looni & Goh, 2020). These studies signal the need for appropriate interventions for training scientists in science communication skills. However, it remains unknown whether Indian scientists feel they have enough communication skills or need some training to enhance their engagement with the public and the media.

2.19. Need for science communication specialists

When scientists have their limitations to engage, many studies suggest having professional science communicators or science communication departments/units at R&D institutions to facilitate science communication efforts (Royal Society, 2006; Searle, 2011; Merino & Navarro, 2018; Navarro & McKinnon, 2020). As noted in the discussion above, scientists cannot be devoted full time to science communication. They may not always be willing to engage or, even when willing, have the necessary skills and other prerequisites to engage the public well. On the other hand, dedicated and passionate science communicators can serve as mediators between scientists and the public. Therefore, trained and skilled science communication professionals or specialists can do much of the public communication of science while also facilitating scientists' engagement. Science communicators at R&D institutions have significant roles to play. They can prepare communication products in the

form of articles, features, press releases, video/audio clips, films, or lectures; create new (and utilise the available) public engagement opportunities; listen to the public views and concerns and prepare appropriate responses through scientist-public dialogue; help scientists hone their communication and media skills; organise science communication training; arrange open-houses and science events such exhibitions, guided tours, and hands-on activities; conduct science-society conclaves; arrange scientist-journalist meets; and arrange and provide translational services from technical to simple and from English to local. All these listed activities are part and partial of the science communication gambit. Of course, all these activities must be conducted frequently to maintain a strong link between science and society. Scientists may not always be available to contribute to all these things. Hence, the need for professional science communicators. In addition to institutional science communicators, independent science communicators can also play an active role in science communication through various freelance options.

The idea of having specialist science communicators is to ensure that their primary job is science communication, where they can always focus on delivering better PE results. If science communication is assigned as an additional task to a scientist or any other official at the institutional level, then it just becomes a formality.

However, there are hardly any R&D labs/institutes in India with professional science communicators on their payroll or separate science communication departments. In this context, the proposed new (draft) policies (STIP 2020 and SSR Policy 2019) give a ray of hope for establishing science communication wings at every public-funded S&T institution. However, it remains unexplored what Indian scientists think about the need for science communicators in general and at R&D institutions in particular.