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An agenda for science communication research and practice

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Science should not unilaterally dictate individuals' decisions or public policies. Yet, it provides a vital source of information for societies and individuals that can often improve outcomes and well-being. This requires, however, the effective communication of scientific information. We identify two paradigms for science communication. One focuses on dissemination, often seeking to inform, reframe, or correct beliefs. Another emphasizes participation and engagement with the goal of improving public understanding of science and scientists' understanding of the public's concerns, needs, and values. We argue that participatory approaches better address contemporary challenges concerning scientific uncertainty, politicized science, artificial value neutrality, and a reactive science communication infrastructure. These approaches though need to move away from transactional partnerships toward more cocreation and coproduction of knowledge. They also need to focus more on less motivated and/or engaged populations. Investment in a participatory infrastructure is crucial given that even the most path-breaking science only matters if it can be adequately communicated to relevant stakeholders.

science communication | health communication | scientific literacy | dissemination | participatory research

The 21st century brought with it a radically new communication ecosystem. The internet and then social media amplified actors who challenged the cultural authority of science and expertise. This came as science itself was shifting from a production and consultative stance to what some have called an era of postnormal science (1). Scientific breakthroughs like novel genome editing technologies and AI introduce immense uncertainties about their societal impacts. They also significantly raise the stakes if unintended adverse consequences occur. Postnormal science, as a result, often triggers value disputes across different stakeholder groups (2). In the United States, in particular, many of those value debates have been conducted along political fault lines, with climate change being a prime example. These developments occurred concomitant with substantial demographic and political changes in the United States (e.g., heightened partisan divisions). This mix of an altered communication environment that optimizes outrage and filter bubbles, polarized politics, and compositional changes has contributed to a corrosive amalgam that is challenging the country's basic institutions (3).

The timing of these developments aligned with a renewed focus on evidence-based science communication within the academy, driven partly by former National Academy of Sciences (NAS) President Ralph Cicerone's concern that the "sharing of information and communication with the general public and with policymakers [is becoming] an increasingly difficult task" (4). This led to the first of five National Academy of Science's colloquia on science communication in 2012, co-organized by Cicerone, NAS Vice President Barbara Schaal, American Academy of Arts and Sciences chief executive officer Alan Leshner, Carnegie Mellon's Baruch Fischhoff and one of the coauthors of this essay (Scheufele). The publication of the *Oxford Handbook of the Science of Science Communication* (5) and increasing investments from private philanthropy facilitated a National Academy of Sciences, Engineering, and Medicine consensus study on communicating science effectively (6), and a subsequent standing committee on science communication—which two of the coauthors chaired (Ellenbogen and Scheufele) and the other two coauthors sat (Druckman and Yanovitzky).* A goal of the committee is to advance research on science communication through an iterative exchange between practitioners of science communication and social scientists studying effective tools for public communication and engagement with science.

The articles in this symposium come out of a committee convening. In this essay, we reflect on challenges to science communication, two generalized approaches to science communication, and what we view as the advantages of shifting away from the traditional dissemination paradigm to a framework that focuses on participation and engagement. As we explain, the latter approach more effectively addresses the challenges of scientific uncertainty, politicized science, artificial value neutrality, and a reactive science communication infrastructure. That said, substantial challenges remain, highlighting the need for a strong commitment to the continued development and increased reliance on the science of participatory science communication. Doing so, we believe, will improve quality of life and temper the growing polarized trust in science.

Science Communication Challenges

The role of science in societal decision-making has forever been contested (7). Such contestation has an upside since competition with alternative ways of knowing (e.g., intuition, religion) induces accountability: Science needs to provide

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useful guidance to build and maintain its trustworthiness. This requires that science stakeholders (e.g., scientists, funders, universities, research centers, science museums, science journalists) overcome communication barriers to ensure optimal contributions to well-being. In recent times, at least four classes of challenges have been apparent: uncertainty, politicized science, posing science as a value-free practice, and a reactive communication infrastructure.

First is uncertainty. This includes the inherent uncertainty that comes with science as well as the ability to be nimble in the face of acute, unpredictable crises. COVID-19 exemplifies the latter situation. An October 2019 Johns Hopkins report concluded that the United States was relatively better prepared than every other nation to deal with a pandemic in terms of prevention, detection, response, health care, risk environment, and so on (8). Yet, by September 2020—only six months after cases first surged—America accounted for more than 20 percent of all COVID-19 deaths despite accounting for only 4 percent of the world's population. By the end of 2022, the share stood at 17 percent (9), even though the United States led the way in the development of COVID-19 vaccines. While many factors were relevant to the country's COVID-19 performance, an inability to transparently communicate surely played a role, starting with the misleading messages about masking early in the pandemic (10, 11).

A second challenge concerns politicized science, where political actors use faulty science or dismiss credible evidence in pursuit of an agenda (12–14). While politics played a role during COVID-19 (15, 16), climate change serves as the quintessential example. In the United States, from the end of the 20th century to the first part of the 21st century, politics evolved from being peripheral to central in climate change and environment discussions: "over the course of a little more than 20 years, the environment was transformed from the least to the most polarized issue…" (17). For instance, in 2010, the division between Democrats and Republicans in viewing climate change as a major threat was a nontrivial 36% (61% for Democrats versus 25% for Republicans), but by 2023, this division grew to 55% (78% versus 23%) (18). Politicized science can stymie reliance on sound information as individuals focus more on the perceived partisanship of the messenger than the content of the message (19, 20).

Third, politicized contexts have lured scientists into artificially positioning science as value-free, particularly when feeling attacked in societal debates surrounding postnormal science. This tendency among experts to "defend" science from "climate deniers" or "antiscience" audiences, more often than not, ignores the fact that our scientific evidence base and societal values jointly shape public policy. NAS President Marcia McNutt summarized this challenge for the scientific community eloquently in a commentary following the 2024 US Presidential election: "The scientific community must … better recognize that it may not be helpful to emphasize consensus in policy reports' recommendations when the underlying values are not universally shared … [A]lthough science can affirm that climate change is happening and is primarily caused by anthropogenic greenhouse gas emissions, science can only predict the outcome of the various policies that might be enacted to address the problem. It is up to society and its elected leadership to decide how to balance these options" (21) In the end, some values have to be chosen. This is not only true for policy but also for what is prioritized in crafting science communication and engagement. Given that science can be thought of as a public good, we take the normative position that broad and equitable access to science should be a priority.

Finally, there is a reactive science communication infrastructure. There is a scarcity of dedicated funders, consensus best practices, commitment to data sources, and sustained cross-disciplinary collaborations, all of which are needed to construct a prepared, proactive evidence base and communication network. To be clear, each of these field-building components exist in some guise, but they are embryonic and often ignored. When crises emerge (e.g., a pandemic), communicators tend to not rely upon the existing empirical base about effective science communication strategies, instead relying upon their own intuitions, scientists' instincts, cognate fields (e.g., advertising, marketing), or what they believe to be new—but highly reactive—guidance. Put another way, with each new science communication challenge, stakeholders turn to whatever is most accessible instead of insights from the science of science communication. This reflects a practical indifference to research about effective science communication and engagement (22, 23). Scientists themselves often fail to recognize or do not use knowledge about best practices for science communication (6), do not evaluate their own practices to build an evidence base (24), and/or engage in paternalistic interventions (25). This divide between scientists and science communication researchers undermines the efficacy of science and its potential impact on endline users and policymakers.

We next turn to two stylized portraits of paradigms of science communication. These portraits simplify considerable nuance within each paradigm. Even so, we argue that the aforementioned circumstances mean that predominant top–down dissemination approaches may not be as effectual as bottom–up participatory approaches. Both perspectives have insights to add, but the relative utility of each has shifted.

Dissemination Approaches to Science Communication

The prevailing models of scientific communication implicitly or explicitly proceed from a top–down dissemination perspective. Communication is viewed largely as a unliteral process where speakers transmit content to an audience. A common aim involves addressing deficits and pathologies with communications that, in essence, seek to "correct" a belief or behavior—the goal here is dissemination. This includes providing people with scientific information to close gaps in literacy or epistemic knowledge (26), reframing a topic to alter opinions in a normatively desirable direction such as support for climate change initiatives (27), or intervening to prevent or update misperceptions as was widely discussed during the so-called COVID-19 "infodemic" (28). While not always as blunt, the underlying approach is summed up by Dr. Anthony Fauci: "What scientists have to do is just stick with the science and stick with the data. It is very frustrating when you're dealing with individuals, institutions, or groups that actually deny the reality or make statements that are not backed by facts. You can't get rattled; just make sure you stick with the science" (29). Much of the work from this perspective focuses on estimating average effects of various messages on attitudes and/or behaviors, an approach that became ever-present during COVID-19 (30). For instance, Athey et al. aggregate 819 social media experiments aimed at increasing COVID-19 vaccination rates and estimate they shifted opinions toward vaccines by about 1% (31). While this suggests some impact, the general effectiveness of many of these approaches remains debated (32, 33).

This work has offered some crucial insights and will continue to play a role in science communication research. Yet, societal changes have seemingly made it more difficult for top–down approaches to meet the challenges of communicating science. First, the changed information ecosystem has created a substantial hurdle when it comes to dealing with uncertain scenarios. Science communicators now must compete not only with an enormous range of competing information but also with pseudoscientists who can present themselves as experts. These entities can exploit ambiguity to undermine science; for example, a stream of research shows that a simple statement about the uncertainty inherent to all scientific information undermines the impact of consensus scientific reports (19, 34, 35). In contexts defined by uncertainty, such as an unfolding crisis, this makes top–down science communication particularly vulnerable. This does not mean that the communication of uncertainty should be avoided, or that there are no ways to do so effectively (36, 37). Rather, the point is that communicating uncertainty in a unilateral fashion is difficult and its success highly contingent (38).

Second, politicized science and political polarization have created distinct challenges for dissemination approaches. Trust in scientists has polarized in many parts of the world (39), including the United States. In 2000, 47% of Republicans and 46% of Democrats expressed a great deal of confidence in the scientific community. By 2022, the figures were 28% for Republicans and 53% for Democrats (40, 41), a trend that began well before the COVID-19 pandemic (42) and one that is not simply an artifact of climate change polarization (14, 43). Concordant with these trends, scientists themselves appear to have moved to the left (44), and partisans, particularly Democrats, vastly exaggerate the other side's scientific beliefs (45). These perceptions, in turn, politicize science since individuals come to believe scientists with homogenous political beliefs pursue ideological agendas (46). This can undercut top–down communications aimed at closing partisan divides on scientific issues. For example, a recent megastudy tested 11 promising climate change messages (e.g., norms, consensus statements, frames), concluded "the interventions' effectiveness was small, largely limited to nonclimate skeptics, and differed across outcomes [beliefs, policy support, behaviors]" (47). In short, politicized science makes it difficult to use direct messages to reach those with lower trust who, in many countries, are on the right.

A third, related challenge, concerns utilizing evidence in translating scientific insights into meaningful communications. On the one hand, top–down approaches regularly offer evidence about the effect of given interventions—such as the Athey et al. study cited earlier (31). On the other hand, evaluating "success" has become increasingly difficult due to demographic change. The increasing demographic diversity of the country (48) means that messages that resonate, on average, likely work for some segments of the population and not others, with the "not others" becoming larger over time. A nascent stream of work explores heterogeneities in top–down messages, but as with health and science data more generally, there is an entrenched focus on "average effects" with much less a priori attention to understanding variations among subpopulations (49): "inequalities in health and communication operate together and exacerbate each other, often through [a] mechanism in which access to information, literacy (be it in relation to a language, media, or health literacy), and trust play vital roles" (50). Indeed, an analysis of public service announcements about COVID-19 show the announcements rarely mentioned group differences in the risk of infection despite there being dramatic disparities [(51); also refs. 52 and 53]. This means ensuring equitable access—where variation is as prioritized as a central tendency—is undervalued. In short, it compromises the goals of equity and engagement.

When it comes to the last challenge—a reactive infrastructure—communication technologies have altered both sources of data and the way research is conducted. A major data source through which to communicate is social media. Yet, as Krause et al. make clear in their symposium contribution (54), the proprietary nature of these data means a part of the research infrastructure is outside the control of researchers, or accessible to only select scholars who partner with companies. An unrelated development in research infrastructure has been the rise of research teams, across geographic areas that can now easily communicate with one another. Yet, these teams which increasingly have access to resources have become highly stratified to include only those from elite, highly ranked institutions who have low social distance to one another (55, 56). In both senses, research networks and infrastructure have become relatively exclusive.

This work has generated large-scale research collaborations on health communication (57), social media (58), and polarization (59), some in partnership with civic or commercial organizations. The projects contribute to and reflect infrastructure for the dissemination of research and for communication between scientists and nonscientists. Yet, they also, perhaps inadvertently, contribute to reactivity because of inattention to engagement and the building of an engagement infrastructure. The focal point becomes gathering large amounts of data to test aspects of information dissemination in contexts that become available. Attention to engaging with relevant, broad-ranging stakeholders becomes secondary and is difficult given the centralization of research networks with limited social distance. The consequence is inadequate proactive systems of communication. Indeed, a massive review of COVID-19 research finds that social scientists offer many key insights (60). Yet, the review's authors also recognize the limited influence of social scientists, encouraging "academics… to proactively engage with organizations delivering public services to find out where and what input they would value."

Such efforts are possible. Examples from the United States during the COVID-19 pandemic include contributions from the Societal Experts Action Network that cataloged surveys, provided research updates, and connected experts to policymakers. Alternatively, the COVID States Project collected state-level public opinion data to track disease, behaviors, and institutional trust and made its findings accessible through public reports and data dashboards. While these projects surely reached wide-ranging audiences, there were limitations insofar as the infrastructures were largely built in the moment. It would be useful to maintain and expand these efforts to ensure proactive coordination between what is provided and the needs of diverse, local stakeholders.

Participatory Approaches to Science Communication

Distinct approaches to science communication focus on dialog or participation (61). Instead of the dissemination of knowledge via unilateral translation and transmission, the dialog model aims to promote two-way conversations between scientists and the public. The goal is to improve the public's understanding of science and scientists' understanding of public concerns, needs, and values regarding science. Alternatively, a participatory model of science communication, which has existed for decades (62), has been gaining more traction in recent years in response to growing calls from within and outside the scientific community for greater democratization of science and intentional centering of inclusiveness (63). Participatory models elevate science engagement as a primary goal (rather than altering opinions and behaviors).

Unlike dissemination models of science communication, "engagement" naturally invites greater attention from scholars and practitioners to how audiences encounter science across settings (62), as is made clear by Pandya et al.'s symposium paper (64). Opportunities to experience science have long been at the core of many formal and informal science learning initiatives such as those taking place in schools, museums, science centers, and through citizen science (now called participatory science) activities. The experiences they afford have been shown to motivate learning and trust in science (65). However, not all audience groups have the capacity, motivation, and opportunity to participate in science unless deliberate actions are taken to promote inclusive and equitable science engagement. This recognition, in turn, motivated the rise of community engagement as a critical component of effective science communication. By integrating community expertise, participatory research projects are better equipped to implement programs that benefit communities (66). Community engagement is thus integral to the translation of scientific knowledge (67, 68).

Participatory approaches have downsides, as we will discuss, but also come with advantages in terms of addressing science communication challenges. First, inherent to a participatory model is that potential consumers of scientific information typically have greater access to the scientific production process. This occurs because individuals often will have the capability to ask questions and learn details, thereby directly embracing uncertainty. Extant work suggests doing so may have short-term costs but have long-term upsides. For instance, one paper finds that transparency in sharing negative information about COVID-19 vaccination (e.g., comparing it negatively to the flu vaccine) decreases vaccine acceptance (69). Yet, the same paper notes that embracing transparency and uncertainty can have longer run positive consequences because it builds (or solidifies) trust in science (70). In short, uncertainty can undermine short-term unilateral communications but also can build trust for longer-term relationships common in the participatory paradigm. Here, embracing uncertainty is a part of the approach.

Second, a participatory approach (ideally) puts the potential users of scientific information on an equal level with communicators. This type of engagement can be used to address the challenges of politicized science that stem from the mismatched identities problem of polarization (i.e., science communicators are from different political and demographic backgrounds than many audience members). It does so because achieving engagement in the first place requires the building of trust. Rios et al.'s symposium contribution discusses the importance of intellectual humility in this process (71). They explain that top–down deficit "models of science communication—that lay people are misinformed, uneducated, and therefore the 'problem' whose views must be corrected in contrast to scientists whose position is 'correct'—are inherently lacking in intellectual humility." This argument aligns with work on polarization that sustained engagement across lines of differences can depolarize and lead to more willingness to compromise (72), particularly when accompanied with intellectual humility (73, 74). Engagement and/or listening is a feature of participatory science communication as well as a way to depoliticize.

Third, turning to values—participatory approaches do not invariably ensure more equal access (75) and they often can be relatively intensive. However, they also are more inclusive as demographic and stakeholder variability is a feature rather than a bug [as is made clear in Bednarek et al.'s symposium paper (76)]. The process/ideal infrastructure, as articulated in Pandya et al.'s paper (64), involves shifting the focus from an intended outcome or effect to a focus on engagement as a dynamic process of continued dialog, exchange of perspectives, and renegotiation of values to build trust and enrichment of relationships over time.

Fourth, from an infrastructure perspective, participatory models involve proactive engagement that puts communicators in a better position to make a difference. The relevant actors are many: not just scientists, academics, government officials, social media companies, and the public, but also bridging (intermediary) organizations, community actors (museums, religious entities), practitioners (medical doctors), influencers, and corporations (e.g., pharmaceutical and the AI industry). Of course, this introduces its own challenge of developing infrastructure to facilitate multiple relationships. An excellent example of such infrastructure is the Transforming Evidence Funders Network (TEFN) as detailed in Bednarek et al.'s paper (76). The system identifies funding priorities, sets expectations through funding criteria, assesses proposals, supports implementation, and evaluates the impact. Bednarek et al. provide details on how this process works. The idea is to establish a priori understandings of how to best connect with communities, before scientific challenges emerge, and, ideally, with actors who make policy decisions. The infrastructure provides adaptable guidelines for engagement with communities (e.g., respect, humility and listening, reciprocity, mutuality, reflexivity), as detailed in Pandya et al.'s paper (64). There of course is always some reactivity in scientific responses, but it is less so when connective networks between scientists, communities, and communicators exist.

Proximate Challenges to Participatory Approaches. We have emphasized the advantages of participatory approaches to meet contemporary science communication challenges. Yet, its own challenges are inevitable and here we focus on two we consider most "proximate," meaning in need of addressing in the near term. First, current participatory engagement practices are inherently transactional—that is, they prioritize the agendas of scientists and their sponsors—as opposed to transformational, i.e., seeking to empower communities to address underlying causes of disparities and inequalities, as detailed in Pandya et al.'s paper (64). Moreover, applications of community engagement are primarily motivated by the notion of "science in service of society," but not also consideration of how science and scientists themselves can benefit from such practices by leveraging knowledge and practices developed in communities [see Rios et al. paper (71)]. In this regard, calls from scholars and funders for greater investments in cocreation or coproduction of knowledge, where citizens play a role in every stage of the scientific process, would allow for new science communication infrastructure to be built [see Bednarek et al.'s paper (76)]. This will be vital to leverage the aforementioned building of trust via transparency.

Second, the body of knowledge available to inform effective science engagement practices is almost exclusively derived from experience with audiences who are ready and motivated to engage with science. By comparison, we know less about how disengaged audiences, whether by choice or because they are not invited to participate in science, experience and interact with scientific concepts and how they define and understand science engagement (77). Given the challenges to science communication posed by increasing levels of polarization and misinformation, as well as varying trust in scientists, closing this gap in current knowledge is highly relevant to effective science engagement. Put another way, participatory approaches that employ dialog with humility can help address politicized science but cannot provide insight into how to incorporate less engaged and less motivated individuals. The two challenges we have highlighted reveal a gap between the aspirations of participatory science communication—to put scientists, communicators, and audiences on equal footing and equitably reach heterogeneous populations—and the current reality. These are vital challenges to building trust that often requires "forging a common identity among multiple subgroups while recognizing their distinctive differences and needs" (78).

A Way Forward

We conclude with three suggestions for science communication researchers and practitioners. First, be proactive rather than reactive. This echoes one of the challenges we already pinpointed, but we repeat it because it is so central to science communication, regardless of the approach one takes. The field has been mostly reactive rather than proactive at the science-public-policy space, often responding to external challenges (e.g., misinformation, polarization, AI) and/or the agenda of other fields (e.g., health, STEM education). While these activities are important, the field needs to engage in more ongoing conversations with other disciplines and fields of practice. This will ensure the understanding of what science communication is (i.e., a scientific field itself) and ensure the evolution of the field. This requires actively seeking to influence the agenda of other fields, adopting a design perspective (e.g., designing public dialog, tools for connecting lay people with science that do not involve education) and attending to how communication infrastructure can catalyze and synergize cross-level links and processes (rather than target one level at a time). As one of us wrote, such activities would:

> go a long way toward not being caught as flat-footed as we were during the COVID-19 pandemic. When the pandemic started, we did not have the evidence base necessary to quickly diagnose problems within particularly vulnerable communities. We had not conducted enough studies with relevant populations that would have helped us better understand the mechanisms that blocked channels of communication with them. And our intuitions were often wrong when public health and other practitioners proposed solutions that were largely uninformed by decades of research in the science of science communication (30, pp. 301–302).

Second, there needs to be more attention to ethical considerations in terms of one's goals. Specifically, the dissemination approaches typically operate from a presumption of "fixing" a deficit or pathology to achieve a particular outcome. That introduces concerns about privileged outcomes favored by scientists or practitioners (79) and engaging in social engineering (80). We recognize that this can create a difficult tension when facing antiscience or science denialism attitudes (42). A distinct ethical issue that requires discussion concerns the selection of populations to study in a "fair" fashion accounting for the reality that some will decline involvement (81).

Finally, there are thorny professional considerations; in the traditional dissemination approaches, the relevant networks that shape professional reviewers are researchers, government entities, and corporate sources. This contrasts with participatory approaches where communities and partnerships matter. If participatory approaches are to be embraced, professional evaluations need to appreciate the time and resources required. It does seem as if there is energy for this kind of work with the current President of the NAS stating, "Building trust will require more active listening to affected communities" (21). Democratizing science is not easy of course as the NAS itself has experienced when it dissolved a study aimed at combining Western and Indigenous approaches to understanding the natural world (82). Just as science itself is not easy, neither is its communication. As we have emphasized, there is a *science* to science communication (5).

Where does that leave us? Politicized science within the current information ecosystem means that in many cases, the loudest and most extreme voices receive attention. Consequently, people self-identify or become depicted as "for" or "against" science. This is not only simplistic, but it misses the reality that science is a public good that can improve individual and societal well-being when it is used reliably to inform policy choices. For now, the production of science may often still be a top–down process, but its consumption has always been a bottom–up reality—science's salubrious effects manifest most when those for whom it is meant are engaged in its communication. For these broad societal discussions surrounding emerging science to occur in a constructive fashion, there needs to be an active commitment to continued development and increased reliance on the science of (participatory) science communication. An ongoing iteration between empirical social science and evidence-informed practice will also boost trust in and use of science among those who are historically underserved or mistreated by science, and, of equal importance, build trust in and understanding of those very communities among scientists and science communicators.

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