Editorial: The shadowlands of (geo)science communication in academia — definitions, problems, and possible solutions

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Abstract.

Science communication is an important part of research, including in the geosciences, as it can benefit society, science, and make science more publicly accountable. However, much of this work takes place in "shadowlands" that are neither fully seen nor understood. These shadowlands are spaces, aspects, and practices of science communication that are not clearly defined and may be harmful with respect to the science being communicated or for the science communicators themselves. With the increasing expectation in academia that researchers should participate in science communication, there is a need to address some of the major issues that lurk in these shadowlands. Here the editorial team of *Geoscience Communication* seeks to shine a light on the shadowlands of geoscience communication by geoscientists in academia and suggest some solutions and examples of effective practice. The issues broadly fall under three categories: 1) harmful or unclear objectives; 2) poor quality and lack of rigor; and 3) exploitation of science communicators working within academia. Ameliorating these will require: 1) clarifying objectives and audiences; 2) adequately training science communicators; and 3) giving science communication equivalent recognition to other professional activities. In this editorial, our aim is to cultivate a more transparent and responsible landscape for geoscience communication—a transformation that will ultimately benefit the progress of science, the welfare of scientists, and more broadly society at large.

1 Introduction: Science communication and geosciences

Science communication is a broad field that has been growing and evolving over the last few decades. At the start of this century, its remit and scope had expanded, with Burns et al. (2003, p. 183) framing it as “the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science: Awareness, Enjoyment, Interest, Opinion-forming, and Understanding.” Since then, over the following two decades, the theory and practice of science communication has continued to broaden, drawing in an ever-wider set of different actors and disciplines. As a result, this definition appears limited and outdated now.

In the 1980s, the initial motivation behind the Public Understanding of Science (PUS) movements was the "deficit model," which assumed that the public's skepticism towards modern science was caused by a lack of scientific knowledge, implying that the public received information passively. The belief was that scientists should convey more information to the public to change opinions and develop a positive attitude towards science. However, it is now understood that public communication of science is far more complex than the knowledge deficit model suggests. Despite the persistence of the discredited deficit model in scientific circles (Cortassa, 2016; Simis et al., 2016), even its core practitioners recognize the need to reconsider science communication in light of a deeper understanding of contemporary society. While most practitioners agree with Fischhoff and Scheufele (2013) that communication is a two-way process, wherein scientists must both listen and speak, Fischhoff and Scheufele argue this process should adhere to the same rigorous standards of evidence as science itself. They advocate for science communication grounded in existing research and subjected to empirical evaluation, rather than relying on intuition. In contrast, others, such as Bucchi and Trench (2021), prefer to view science communication as a social conversation, expanding the concept of quality beyond mere impact or effectiveness and encouraging a multifaceted understanding where the evaluation should not be based solely on the assessment of one participating party.

These contrasting viewpoints are important because science communication is a crucial component of research as it can benefit society, advance scientific understanding, and make science more publicly accountable. Oreskes (2020) argues that scientists have a moral obligation to inform society about threats that non-experts cannot identify on their own. However, she also cautions that expertise is specific, so scientists must respect the expertise of others, implying an obligation both to speak and to listen. Scientists need to communicate within their domains of expertise and respect the knowledge of professionals in other areas (Oreskes, 2020, p. 43). This is particularly the case within the field of geosciences, where geoscientists are working on many topics directly relevant to human and environmental well-being. Cross and Congreve (2021) assert that to address "wicked problems" like climate change and those related to disaster risk management, academics must possess strong communication skills in addition to their technical expertise. They believe it is the duty of Geoscience educators to help undergraduate students and young people, more broadly, develop these skills.

Surveys indicate a high level of public trust in scientists, especially those in universities (Krause et al., 2019; Goldenberg, 2023). This trust places scientists in a unique position as communicators. Because people listen to and trust scientists, they expect them to disclose important information (Thompson et al., 2023). Scientists, aware of their unique position, feel responsible for sharing sensitive information with the public. Given the diverse communication channels between academics and the public, academics must handle these channels carefully, clearly acknowledging and explaining uncertainties. The public often expects academics to have all the answers and not make mistakes, as seen during the COVID-19 pandemic. This requires scientists to be clear, effective, and thoughtful communicators, as well as kind, empathetic, and humble.

Furthermore, the range of channels employed for communication is diverse, spanning from science journalism and institutional communication through social media to public relations and marketing. It extends further to encompass museum exhibitions, science events organised by cities and countries in collaboration with marketing and event management firms, science centers, science cafés, science slams, science blogs, and more. Weingart and Guenther (2016) add that even the traditional role of providing scientific advice to policymakers has been rebranded as science communication. Weingart and Guenther (2016) highlight that science communication has evolved into an industry over the past few decades. It is no longer solely undertaken by a few dedicated scientists, science journalists, or popularizers with the intention of informing an interested public about the latest research advancements and their broader societal implications. Instead, science communication has become a battleground where various stakeholders compete for attention, power, and influence due to financial interests, job opportunities, and professional identities. Consequently, even the definition of science communication itself is subject to debate and contention. Given this plurality in definitions and practices, it is important to acknowledge the spectrum of science communication and communicators.

For the purpose of this editorial and the *Geoscience Communication* (*GC*) journal, we refer to Hillier et al. (2021, p-494) for a working definition of science communication: "We use the term "geoscience communication" to refer to the range of activities included in *GC*; these fall within a spectrum. At one end is activity-led work that might variously be known as education, outreach, communication, or engagement (e.g., science theatre as a medium for effective dialogue), and at the other end is curiosity-led research (e.g., how video games tangentially communicate geoscientific concepts) into how people engage with geoscience."

GC engages with geoscience communication and communicators in five broad areas (Illingworth et al., 2018), illustrated by recent *GC* articles that embody these areas:

- *Geoscience education*: McGowan et al. (2022) explore the potential for using video games as a tool for teaching geoscience, specifically the geology and geomorphology of Hokkaido, Japan.
- *Geoscience engagement*: Fonseca et al. (2022) focus on the way physical concepts like the jet stream are represented in the press
- *Geoscience policy*: Brimicombe et al. (2022) investigate the bias of reporting various climate risks in English-language news articles.
- *History and philosophy of geosciences*: Rogers et al. (2022) examine the need for decolonizing the curriculum for geologists.
- *Open geosciences*: Watson et al. (2023) evaluated the dissemination of satellite-based ground deformation measurements through Twitter.

Together, these recent *GC* articles demonstrate the diverse and multifaceted nature of geoscience communication. *GC* provides a supportive platform for geoscientists, educators, and communicators to share their innovative communication approaches. The core purpose of *GC* is 2-fold (Illingworth et al., 2018): (1) to provide wider and more formal recognition for existing and future geoscience communication initiatives, and (2) to better formalise the discipline of geoscience communication. In line with the core purpose of *GC*, in this editorial we highlight systemic issues ingrained in science communication, especially as it relates to the geosciences and geoscientists in academia. We refer to these issues as "shadowlands" hereafter. We also discuss the divergent perspectives and the spectrum of viewpoints among the authors of this editorial to mirror to some extent the spectrum of perspectives within the wider community. Finally, we propose potential solutions for the identified problems, and establish the journal's guiding principles.

2 The shadowlands of science communication

In academia, a lot of science communication, including geoscience communication, in academia happens in “shadowlands”, i.e., spaces, aspects, and practices which are not clearly defined and may be harmful with respect to the science being communicated or for the science communicators themselves. While we discuss these issues primarily in the context of geosciences, it is important to note that these are relevant problems that could apply to other scientific fields as well. We outline three such shadowlands of science communication in academia in this article: 1) potentially harmful objectives, 2) poor quality and lack of rigor, and 3) exploitation of science communicators. We would like to point out that, as the authors of this editorial, we do not share the same views on all topics discussed herein. Our opinions span a broad spectrum, some of which are illustrated in Figure 1.

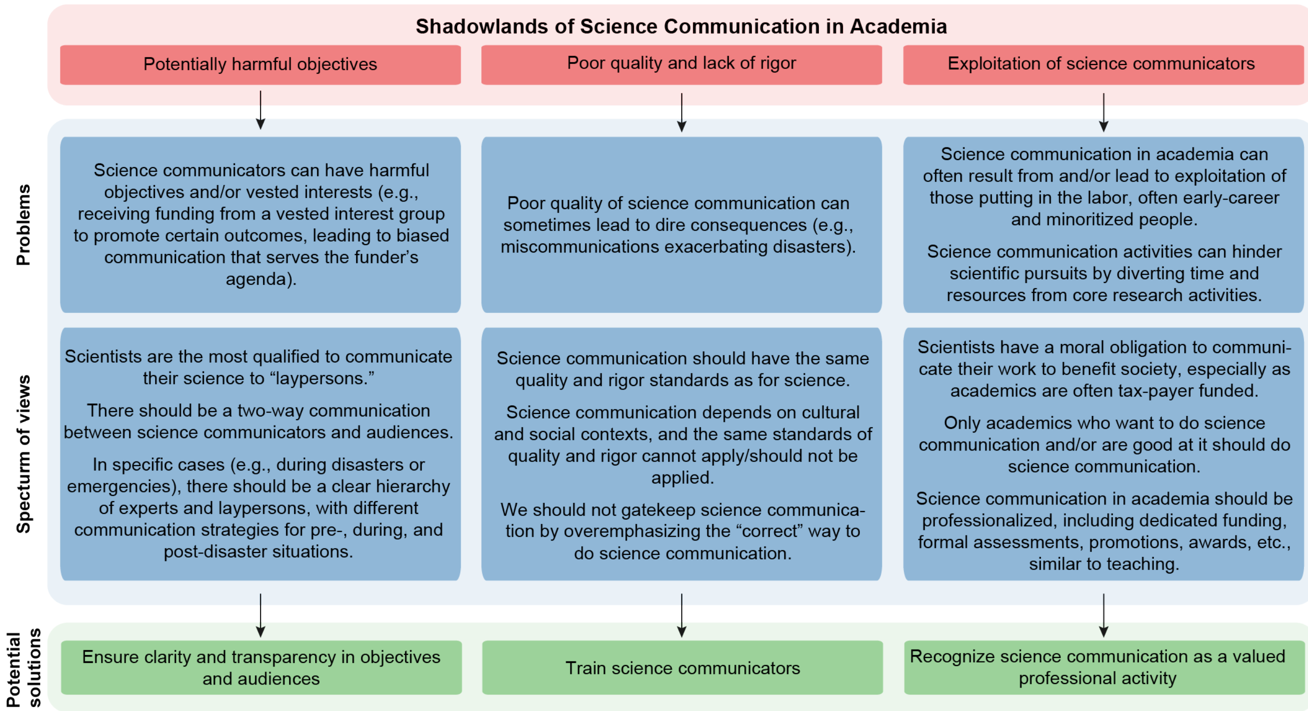

Figure 1: The shadowlands of science communication in academia — problems, spectrum of views, and potential solutions. The issues are discussed in detail in Section 2, with potential solutions addressed in Section 3.

2.1 Potentially harmful objectives of science communication

While science communication is generally regarded as a morally good endeavor, valid concerns exist regarding its objectives, particularly in relation to the motivations of science communicators. A significant concern is the influence of funders—when present—on science communication, potentially driven by vested interests. Beyond the ethical dimensions, fundamental questions arise: What is the primary purpose of the science communicator? On what terms is science "made and sold"? How should we navigate the powerful persuasive tool of storytelling in science? Is success measured by our ability to influence, persuade, and change perceptions and behaviors? Although there may not be a single "correct" answer to these questions, reflecting on them can help us recognize both unintentional internal biases and hidden external influences that could lead to harmful science communication.

The multiple goals of science communication (Besley et al., 2018; Kappel and Holmen, 2019) (Figure 2) raise the concern of potential tension between different aims. This could be the case when the concerns raised by the public differ from scientists' own evaluation of what is best for society's well-being. Resolving such tensions can be difficult; the public's views can be based on serious misconceptions, but prioritising scientists' own conceptions (positionality) of societal well-being can risk being paternalistic. Aside from the issue of tension between many aims, there is also the worry that the goals of professional science communication might conflict with the core aims or norms of the relevant scientific disciplines. For example, most scientific disciplines draw especially careful conclusions on the basis of their data, but such nuances might not lend themselves for "punchy" storytelling preferred in the media. This concern raises its head especially when professionalization of science communication means that "there is money in the game, there are jobs to be captured, and there are professional identities at stake." (Weingart and Guenther, 2016, p-2). Another instance of tension between goals of science communication and the core disciplinary goals relates to "marketing-led" science communication, in which academics through disseiminating their research stories become part of the commercial promotional machine for their universities and research institutions (Stewart and Hurth, 2021).

Moreover, it is important to acknowledge that another significant aim of science communication can be to scrutinize science itself and hold scientists or scientific practices morally and socially accountable to the public. Science has also had, and continues to have, negative or socially harmful effects on society (Jones, 2008). In these cases, the goal of science communication may not be to enhance public trust in science but rather to critically examine and ensure that science is held accountable for its actions. This introduces a potential tension between the goals of benefiting society and benefiting science, where science communication may need to balance promoting scientific knowledge with critiquing and holding it accountable.

Aside from such instances of potential tension, there is also the question of due process — especially regarding the model of communication and valuable attributes of communication. A major challenge with the broader goal of "informing the public" concerns the deficit model, where the public is viewed as having insufficient knowledge of science which is remedied by scientists' successful communication. Although issues related to the deficit model of science communication are well known (see e.g., Sturgis and Allum 2004) it is still regarded a viable model for influencing science policy (Cortassa, 2016; Simis et al., 2016) and there is evidence that scientists endorse it (Besley and Nisbet 2013). With respect to communicative virtues, openness, honesty, and transparency in science communication are usually recommended (e.g., Wilsdon and Willis, 2004; Keohane et al., 2014). However, there have been some concerns raised that exercising these virtues in science communication can undermine public trust in science (John, 2018). The notion of the deficit model is important to note, but equally we should acknowledge that one-way awareness raising mechanisms occasionally have their place, e.g. in emergency risk communication situations where actionable risk messaging is required. In such situations, the emphasis should perhaps be on ensuring that the messages are effective (i.e., received as intended). However in general, both the scientist and the target of the communication must listen, understand, as well as speak.

Many academics find solace in science communication as an antidote to the challenges of higher education, relishing the opportunity to step outside the confines of the ivory tower. As Dooley (2017) notes, when scientists engage in science communication, they should embrace their humanity and use emotions to communicate scientific concepts. This suggests that conversely, inside the ivory tower, academics may feel dehumanised (Wheaton, 2020). For example, academics report a sense of trepidation or fear around the completion of impact statements or when tick-box efficiency takes primacy over effectiveness (Chubb and Watermeyer, 2017; Chubb et.al., 2021). Engaging with socio-economic and socio-cultural topics within science can help academics to get involved with new topics by developing an aspect of inspirational, or activating communication that can be regarded as a form of scholars' engagement (Jünger and Fähnrich, 2020). Our aim here is not to "police" the "right" objectives for academic science communications. As we highlight in the subsequent sections, where we focus specifically on geoscience communication, our intention is to make geoscience communicators and their (potential) funders reflect on the shadowlands of geoscience communication. While there is nothing inherently wrong in pursuing science communication as an antidote to higher education, we believe that it should not come at the cost of quality and rigor of the communication or the exploitation of communicators.

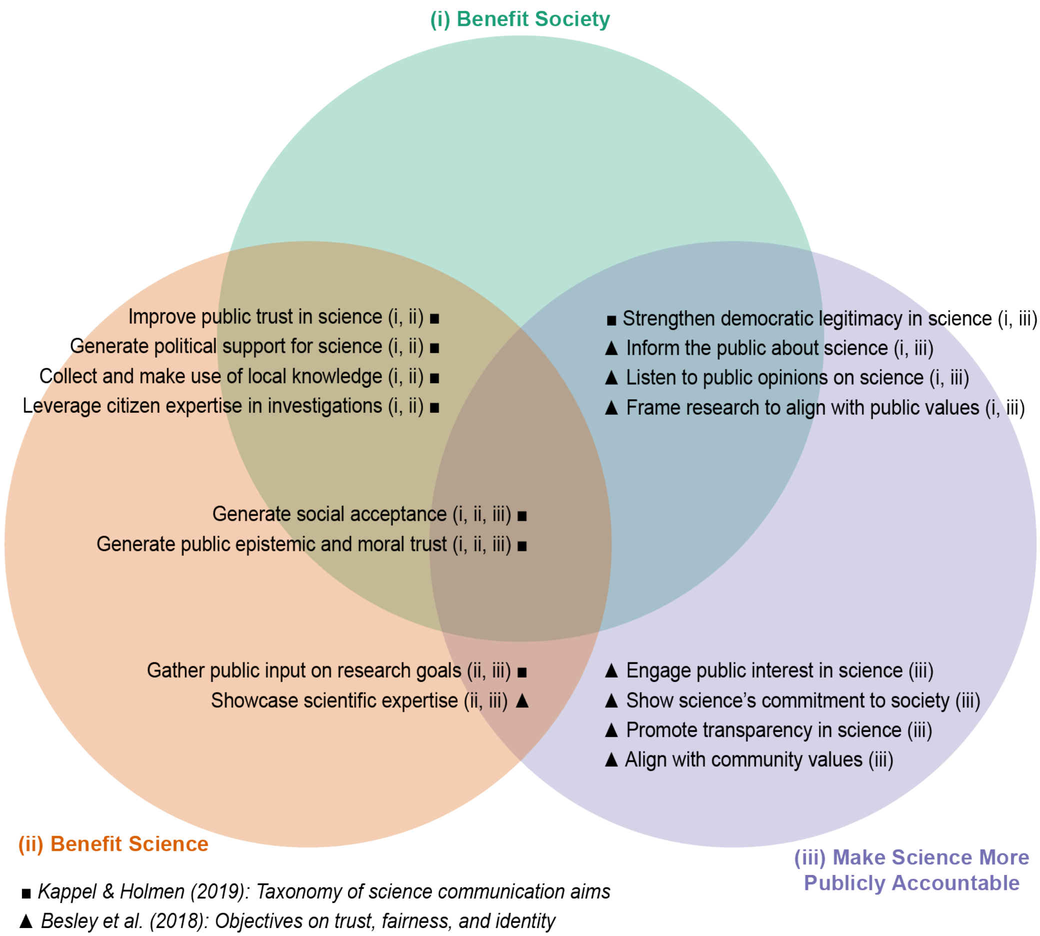

Figure 2: Taxonomy and goals of science communication based on literature. Each goal is connected to broader values, including (i) benefit society, (ii) benefit science, and (iii) make science more publicly accountable. This is a rough categorization, as each of the goals may link to each of the three values.

2.2 Poor quality and lack of rigor

Oftentimes, science communication strategies do not work, and their failure can lead to enhanced disasters and loss of more lives (e.g., when miscommunicating about extreme weather events). In this section, we provide examples illustrating instances of poor quality and lack of rigor in science communication, with a focus on risk communication — a form of high-stakes science communication that occurs when a threat is anticipated but not necessarily imminent. While this editorial primarily targets academia and academics, some examples are drawn from science communication outside academia, intentionally so, since communication from government agencies (e.g., extreme weather and earthquake communication) often involves collaboration with university scientists.

For risk communication to be effective, it needs to capture and incorporate information about the local context in which the communication work is undertaken. Factors such as population characteristics (e.g., language, ethnicity, and race), socioeconomic status, experience and exposure to a range of hazards, and access to and use of information and communications technologies influence the development and uptake of safety messages, and therefore, should be taken into consideration when designing communication outputs for decision making and advocacy in specific contexts. For example, the “Drop, Cover and Hold On” earthquake drills and campaigns considered how Californians behaved in past shakings (i.e., running outside, taking shelter in doorways, etc.), and focused on the much greater likelihood of injury from non-structural hazards (i.e., falling or moving objects) rather than structural damage. To ensure its uptake, earthquake scientists and emergency managers worked closely with sociologists, artists and community participants to capture the regional context in the development and dissemination of disaster risk reduction messages.

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Since 2008, the ShakeOut campaign has gone global, with over 40 million participants registered worldwide for 2022. While there are good reasons to celebrate this, there are also reasons to be concerned. “Drop, Cover and Hold-on" may not be the safest actions to take in highly vulnerable buildings that are small enough to exist safely (such as many of the buildings that collapsed during the 2005 Kashmir earthquake). Therefore, it is important to recognize that there is no single perfect safety message for any nation as each nation has its own customs, beliefs, building, geology and capacities. A scientist who is not aware of local customs and deeply embedded beliefs should exercise caution when communicating safety messages with the public (Geohazards, 2018; Gill et al., 2021).

Hazard maps (in print and online) are another example of unidirectional communication output used by governmental and non-governmental agencies to communicate geohazard risks with the public. Despite their widespread acceptance and use in hazard awareness campaigns and in decision making, their effectiveness in hazard communication has not been rigorously investigated. Setin et al. (2012) give examples of highly destructive earthquakes that occurred in areas shown by earthquake hazard maps to be relatively safe and call for rigorous and objective testing of hazard maps, and evaluation and clear communication of uncertainties with the users. Lack of basic elements of map reading skills is also identified as one of the key barriers to understanding earthquake-related concepts amongst school students in Tajikistan (Mohadjer et al., 2021). While there are a few hazard map studies (e.g., Crozier et al., 2006; Bell and Tobin, 2007; Nave et al., 2010) exploring variables that influence people’s map comprehension such as viewer perceptions of risk, risk area accuracy, preferences for map features, and misconceptions about visualizations, MacPherson-Krutsky et al. (2020) call for more research on assessing the degree to which different factors contribute to high map comprehension levels. Taken together, scientists as creators of hazard maps need to engage in dialogue with a wide range of potential users to rigorously test and improve their communication products.

Good data visualization is a crucial means of communicating complex information in a clear and effective manner. Data visualization alongwith the representation of uncertainty plays a pivotal role in science communication, particularly when communicating complex information such as natural hazards or human-induced disasters. Poor data visualization can contribute to ineffective or subpar science communication, as highlighted by Padilla (2022), who discusses the challenges of conveying uncertainty through maps and emphasizes the need for effective visualization strategies to enhance comprehension of these uncertainties. Clear and accurate representation of uncertainty is relevant for many geoscientific challenges such as aftershock forecast maps (Schneider et al., 2022). The incorrect use of color in data visualization, as highlighted in Crameri et al. (2020), can also lead to misinterpretation of information.

Science communication can often be monodisciplinary. However, as pointed out above, collaboration between scientific disciplines (e.g., scientists studying specific hazards) and those assessing societal risk understanding (e.g., social or behavioral scientists) is essential for effective communication (Fischhoff and Scheufele, 2013). A recent example highlighting the lack of collaboration across relevant fields and science communicators, resulting in avoidable deaths, is related to the COVID-19 pandemic. In the early stages of the pandemic, debates arose regarding the modes of transmission of SARS-CoV-2, the virus that causes COVID-19. Morawska and Cao (2020), along with many aerosol scientists, argued that airborne transmission of the virus was a reality that should be acknowledged and addressed. They contended that the lack of attention to this primary mode of transmission in public health messaging led to a failure to implement adequate control measures, such as masking and improved indoor ventilation. Randall et al. (2021) provide a historical perspective on the transmission of respiratory infectious diseases and discuss how the lack of understanding of droplets and aerosols led to the undervaluation of the risk of airborne transmission for many respiratory infectious diseases, including COVID-19. The failure to recognize the role of airborne transmission in the spread of these diseases and the communication of incorrect science, including by the World Health Organization in the initial days of the pandemic, led to preventable illnesses and deaths.

These examples demonstrate how poor science communication and inadequate science communication systems (including absence of such systems) can have serious consequences and highlights the importance of accurate and clear communication of scientific information. Additionally, there have also been some public discussion of people conflating public discussions on science and its results with discussions within science (e.g., climate change, COVID-19 vaccinations). Whilst scientists publish in scientific journals and on social media (e.g., Twitter, now known as X), “pseudo-scientists” only do the latter but appear to be scientists to many people due to their loud presence on social media and other platforms. The public often cannot distinguish scientists and “pseudo-scientists”, leading to the misconception that there is no scientific consensus where one exists and that legitimate critics are being silenced. This issue also persists within the scientific community, partly due to the belief that uncertainties cannot be understood by decision-makers and the public, and therefore cannot be incorporated into a binary yes/no decision-making process (Pappenberger and vavBeven, 2006). As a result, information is often simplified to remove 'unwanted' uncertainties. However, many decision-makers (e.g., those involved in flood early warning) are well-versed in handling uncertainties, as these are present in many other components of the forecast-based decision-making chain (Arnal et al., 2020; Budimir et al., 2020). Additionally, public audiences can also engage with uncertainties when communicated effectively (van der Bles et al., 2020).

Despite communication being often at the heart of improved response throughout the disaster cycle (Golding et al., 2019), little attention has been given to the systematic evaluation of communication tools used or developed by scientists to inform and engage in dialogue with the public. These evaluations are important because effective communication, especially related to crises, has been shown to lead to more appropriate responses and the acceptance of more flexible hazard management strategies (Steelman and McCaffrey, 2013).

As discussed in the context of risk communication, a linear, unidirectional approach for increasing public awareness does not always lead to action (Neil 1989; Tierney 1993; Fischhoff 1995; Sellnow et al., 2008). An effective communication strategy takes into account the different ways people view risk, as well as their cultural and socioeconomic context, all of which may affect how the risk is understood (Hooker and Capon, 2017; Cormick, 2019). Therefore, interaction and dialogue with those facing the risks can shed light on their risk perceptions and how these relate to taking action (or the lack thereof) and provide essential insights into adapted and effective communication strategies. These factors render the evaluation and comparison of communication difficult, as one approach may be successful in a specific context and ineffective in other situations. While we focus on risk communication in this section, the problems and discussions are relevant to many other forms of science communication.

2.3 Exploitation of science communicators

2.3.1 The labor issue and exploitation of Early Career Scientists and minoritized groups

There is general widespread pressure on all university-based scientists to communicate their research. This applies a workload pressure to everybody, but impact differs according to time pressure, direction from funding bodies and the provenance of academics (Martinez-Conde, 2016; Hillier et al., 2019). Anecdotally, at more senior levels, mental health issues leading to breakdowns, marriage failure, and long-term stress are common symptoms which can arise from emotional exhaustion and overwork (Hillier et al., 2019; Guidetti et al., 2020; Wheaton, 2020). The hyper-competitive funding landscape for senior academics, according to Chubb and Watermeyer (2017), can rely on the "research grants culture", or "game-playing" linked to inflated accounts of impact. There may also be a tendency for more senior academics to displace the task of public engagement onto early career scientists (ECS), or administrative staff – whether funded explicitly, or not, to do this (Pownall et al., 2021; Watermeyer and Rowe, 2022). Despite these increased responsibilities for public outreach, ECS continue to have less established influence or agency compared to their more senior colleagues. The tenure of ECS is predominated by short-term contracts leading to reduced resilience, burnout or depression associated with academic precarity (Fowler, 2015; Hillier et al., 2019; Wheaton, 2020). Consequently, exploitation might have a different pathway and greater impact due to perceived insecurities that are commensurate with the commencement of a career (Pownall et al., 2021).

ECS typically are encouraged to be involved with science communication as an activity crucial to developing the next generation of scientists by improving scientific literacy within the public domain outside of academia (Kompella et al., 2020; Kerr, 2021). The motivations to engage with these activities can conversely be ascribed as constraints as they are associated with the provision of public engagement activity that is identified as low-cost, or a lesser value, and in many cases the mentoring of ECS by mid-career scientists is devalued (Barrow and Grant, 2019; Hillier et al., 2019; Kompella et al., 2020). The potential for exploitation of their labor merits discussion and can be contextualized within the broader concepts of pedagogic frailty, particularly as ECS constitute the most numerous proportion of researchers in higher education (Kinchin and Francis, 2017; Lahiri-Roy et al., 2021; Pownall et al., 2021). The impact of overwork as structural inequality endemic in academia arguably has repercussions on the mental health of science communicators, indicating a clear link between the mental wellbeing of academics and their perceptions of work demands. The prominence of research and public engagement demands is recognized, which suggests the approach to these aspects of academia in terms of the potentially negative consequences of exploitation and over-work, with evidence that these effects are most pronounced amongst marginalized (minoritized) groups (Barrow and Grant, 2019; Guidetti et al., 2020; Hernandez et al., 2020; Wheaton, 2020; Caltagirone et al., 2021).

The spectrum of marginalization occurs at an intersection of gender, race, caste, sexuality, physical ability, Global North vs Global South, and other identities and lived experiences which also influence how we see and study science and society (Canfield et al., 2020; Finlay et al., 2021; Lahiri-Roy et al., 2021). Geoscience, amongst all STEM disciplines, has the lowest percentage of minoritized students and professionals which underlines this equity gap. The field is predominantly White, carrying substantial privilege (Berhe et al., 2022; Dutt, 2020). The visibility of minoritized groups through public engagement is crucially important to breaking down stereotypes (Weingart and Guenther, 2016; Guertin et al., 2022). However, the assumption that minoritized groups must hold key responsibility to counter these affects through active, open and visible engagement pre-disposes marginalized groups to exploitation as communicators who are expected to provide institutionally-led public engagement activity to counter prejudice and be equity-active (Barrow and Grant, 2019). Equity of marginalized groups in higher education is problematic and global discourse signifies a range of perspectives that can be adapted to fit cultural and social priorities. This needs to be tempered with the consideration of the ethics of equity in science communication, which undoubtedly shoulders a greater burden of responsibility to promote visibility of marginalized groups to marginalized science communicators (Barrow and Grant, 2019; Caltagirone et al., 2021; Lahiri-Roy et al., 2021).

The "invisible" work of academia is highlighted by the Social Sciences Feminist Network Research Interest Group (2017) as being a significant time drain on academics looking to develop their tenure and promotion. This invisible work can often be assigned to public engagement professionals, contributing to disproportionate demands on different roles that support science communication (Watermeyer and Rowe, 2022). The notion of invisible work is accepted as a norm within academia, particularly for women, which may lead to the exploitation of public groups by relying on their "free" labor, revealing unpalatable aspects of exploitation derived from in-kind contributions from unpaid co-producers (Social Sciences Feminist Network Research Interest Group, 2017; Carter, 2020; Williams et al., 2020; Vohland et al., 2021). Support in the form of mentoring for women in STEM returning to work following a career break can be beneficial; conversely, it can also reinforce gender stereotyping when females are assigned mentoring roles under the misapprehension that they are perceived as more "motherly," caring, administrative, or outreach orientated (Kompella et al., 2020; McKinnon and O'Connell, 2020). This dynamic underscores the interplay of male privilege, particularly White male privilege, which shields many geoscientists from the pressures and obligations of invisible labor, while minoritized women are burdened with additional and invisible work (Hernandez et al., 2020; Caltagirone et al., 2021).

2.3.2 Science communication activities can hinder scientific pursuits

The "Sagan Effect" refers to the risk that a science communicator may lose their scientific reputation among their peers by simplifying concepts for a broader audience or being too visible (Chen et al., 2023). However, a survey of highly cited U.S. nano-scientists suggests that public communication, such as interactions with reporters and being mentioned on Twitter, can contribute to a scholar's scientific impact (Liang et al., 2014). Martinez-Conde (2016) argues that although most individuals who disseminate science to the public face no significant negative consequences and may even experience some benefits, there is a lack of recognition or rewards for their communication efforts within institutional structures. Nevertheless, there are isolated cases where science communicators have experienced severe consequences. Furthermore, certain scientists from underrepresented groups may be at a higher risk of facing such negative consequences.

The impact of scientific research on society is frequently emphasized in academic job descriptions and promotion criteria. According to Hillier et al. (2019), academic researchers may perceive engaging in knowledge exchange with industry as potentially detrimental to their career prospects due to time constraints. The study analyzes promotion criteria and job advert specifications, suggesting that for researchers to thrive, their impact work must align with other demands on their time, such as research and teaching, which are currently deemed more crucial in academia. The relationship between impact work, research, and teaching might be more of an aspirational goal to meet policy and funder expectations (Williams et al., 2020). Notably, higher-tier higher education institutions appear to have an advantage in securing research grants compared to lower-tier ones, highlighting an equity gap (Papatsiba and Cohen, 2020). Furthermore, while institutional policies often stress the importance of equity, it does not emerge as a significant factor in the promotion process for most academics (Barrow and Grant, 2019).

There are also some interesting parallels between our critique of the shadowlands of science communication to ongoing debates on collaboration and coproduction. For example, Oliver et al. (2019) discuss the concept of coproduction in health research, which involves collaborating with stakeholders in the research process. They identify the costs associated with coproduced research and argue for a cautious approach to coproduction until more evidence is available on its impact and costs. Williams et al. (2020, p-1) respond “Oliver et al. stray too close to ‘the problem’ of ‘co-production’ seeing only the dark side rather than what is casting the shadows. We warn against such a restricted view and argue for greater scrutiny of the structural factors that largely explain academia’s failure to accommodate and promote the egalitarian and utilitarian potential of co-produced research.” Similarly, in the case of science communication, even as we cast light on the shadowlands of science communication, we hope to also highlight the structural issues that cast these shadows.

3 Recommendations for (geo)science communication

The discussion in the previous section highlights the primary barriers for academics to carry out science communication sustainably and fairly, rather than reasons why they should not engage in science communication. The reasons to do science communication are still relevant even if institutional barriers make it hard to do so. In this section we discuss the specific recommendations for problems highlighted in Section 2 along with some best practices.

3.1 Ensure clarity and transparency in objectives and audience

Clarity in science communication pertains to the accurate and straightforward transmission of information, ensuring that the intended message is effectively conveyed and understood by the audience without confusion. Transparency, meanwhile, involves being forthright about the goals, context, and any underlying biases or constraints influencing the communication. Together, clarity and transparency are essential for fostering trust and understanding between scientists and their audiences. Clarity and transparency are critical components of effective science communication. Hutchins (2020) proposes the following protocol to pursue effective science communication:

1. Audience: Who will receive the communication and in what setting?
2. Purpose: What is the purpose of the communication?
3. Format: Will the communication product be oral, written, visual (or some combination), and what constraints does this format impose?
4. Significance: What is the significance of the research for this audience?
5. Get feedback and revise

Understanding the audience and the purpose of the science communication is paramount when tailoring messages to ensure effective engagement. The success of communication is ultimately gauged by the audience's response, making it a critical metric for assessing whether the communication achieves its intended objective. Clarity is context-dependent and involves more than simply simplifying complex information; it requires careful consideration of language, tone, and framing to align the message with the audience's needs. For example, in a technical report aimed at experts, clarity may be achieved through precision and specificity, whereas in public outreach, clarity may necessitate simplicity and engagement.

Going a step further, Stewart and Hurth (2021) argue in favor of the more reflexive, participatory, and interdisciplinary "guide-and-co-create mode." From the perspective of this editorial, science communicators clarifying and being transparent about the objectives and audience of their science communication is also an effective way of countering the harmful and unclear objectives of science communication (Section 2.1).

To tailor communications to specific audiences, it is necessary to create a profile of the audience, including their knowledge level and motivation for engaging in the communication. Additionally, it is important to consider the audience's cultural and social background, as these factors can impact how they receive and interpret information. Similarly, the chosen language of science communication can also be a political question, as academia often incentivizes the use of English, but local communities would benefit from local language(s). As Márquez and Porras (2020, p-5) note, "There is a language bias in the current global scientific landscape that leaves non-English speakers at a disadvantage and prevents them from actively participating in the scientific process both as scientists and citizens. Science's language bias extends beyond words printed in elite English-only journals. It manifests in how science is reported in mass and social media outlets, in the researchers represented in the media, and often in the lack of contact between communities and their local scientists."

Achieving effective science communication necessitates clarity and transparency in both objectives and audience engagement. By articulating the purpose of communication and grasping the characteristics and motivations of the audience, one can craft tailored communication products that effectively engage and inform. Moreover, highlighting the significance of research and fostering collaboration across diverse communities and languages can contribute to building a more inclusive and impactful scientific community. There is no singular approach to achieving this; rather, it requires the cultivation of expertise and competence within a community of practice—an objective at the core of *GC* for the geosciences community.

3.2 Train science communicators

While the importance of science communication is increasingly recognized and emphasized, many scientists do not receive any formal science communication training to develop the necessary skill sets. Science communication is often times done by scientists who are not adequately (or at all) trained in science communication (e.g., in visualization, social science, etc.), where ad hoc solutions are treated as substitutes for expertise in the sciences of communication (Fischhoff and Scheufele, 2013). While there are increasing amounts of informal training opportunities (e.g., academic conferences, talking to peers), to be effective, however, science communication must be part of an academic's formal training (Brownell et al., 2013). However, the opportunities at universities are very often irregular and informal. Examples include participation in community events on campus, science festivals (e.g., Pint of Science), presentation platforms (e.g., Three-Minute Thesis and TEDx), and media interviews.

Researchers training and development needs are summarised well in the Vitae Researcher Development Framework (RDF 2011). *Domain D* of the framework — Engagement, Influence, and Impact — covers the skills and knowledge needed for researchers to work with others and increase impact of the research. *Subdomain D2* Communication and dissemination and *Subdomain D3* Engagement and impact highlight the skills needed to excel in this area of research. Metcalfe (2019) reiterates that there is a divide between science communication models and theories used by science communication researchers and what happens in practice. There are three models described by Metcalfe (2019) — the Deficit model, the Dialogue model, and the Participatory model. Each comes with its own theories and set of necessary skills. However, their analysis of Australian science communication or engagement activities in 2012 discovered that most activities did not align their activity objectives with the underlying theory. More recently, Science Europe (2022) framework discusses a values based approach for organization of research, including for communication and dissemination of research, to facilitate 1) autonomy/freedom, 2) care and collegiality, 3) collaboration, 4) equality, diversity, and inclusion, 5) integrity and ethics, and 6) openness and transparency.

Communication skills form an integral part of researcher activities; however, these are often focused on dissemination of knowledge through outputs like research papers. It is important to identify which skills can be transferred to science communication from researcher development in general and which skills are specific to science communication. Kelp and Hubbard (2020) suggest that communication skills should be part of undergraduate education to establish a solid skills base. The Horizon 2020 project QUality and Effectiveness in Science and Technology communication (QUEST) developed tools, recommendations and guidelines for communicators and practitioners (Costa et al., 2019). The QUEST WP4 summary report provides a comprehensive overview of science communication education across Europe. They recommend four key areas for science communication training: scientific knowledge, educational studies, social studies of science and communication studies. Offering a basic science communication training to all scientist as part of their development programme or studies is a key recommendation, with an element of broader societal context of the research, rather than skills development alone.

Some of the tools and approaches for science communication that should be taught are: conducting interviews, designing surveys, qualitatively/quantitatively analyzing interview/survey outputs, a basic understanding of ethics, designing serious games, storytelling, taking part in public debates, and working with artists, art curators, and art spaces. These tools should also target online communication and interaction (including on social media) and digital content creation (Bubela et al., 2009). Furthermore, training scientists in communication methods based on social science research and techniques that involve the community in scientific issues will help challenge the deficit model and make science communication more effective (Simis et al., 2016).

More broadly speaking, we define the following three types of training needs:

1. One-way communication: Training for one-way dissemination of science and scientific work focuses on the skills used by journalists and media professionals to present science in a compelling narrative form.

For example, writing a news article about a recent scientific discovery or creating a documentary that explains complex scientific concepts to a general audience.

2. Two-way communication: When the communication aims to inform the public about socially contested ideas and issues (e.g., climate change, vaccination, genetically modified organisms), understanding the 'science of the public'—such as audience analysis and cognitive and social psychology—becomes crucial. This type of training helps scientists engage in dialogues that allow for more targeted and effective messaging.
3. Three-way communication: The goal here is to contribute scientific input to broader "social conversations about science," such as those in deliberative forums like citizen juries, assemblies, or community-centered engagements. This approach empowers individuals to use scientific knowledge for their own purposes, requiring training in participatory and facilitative skills.

To improve science communication, Fähnrich et al. (2021) recommend that science communication programs and trainers focus on developing students' mental models and perceptions of the changing societal framework in which science communication takes place. This can be achieved by offering new insights, encouraging the adoption of new perspectives, supporting observations and reflection, and challenging existing worldviews. Incorporating science communication training for geoscience students into their study programs at an early stage (e.g., undergraduate level) can foster a better communication culture between scientific disciplines and different public audiences (Brownell et al., 2013).

As with scientific publishing, there is also a case to be made for "slow science communication" – prioritizing high quality over rapidness and quantity (Frith, 2020). Outcomes and impacts of science communication can also take time to bloom and hence may be hard to measure and demonstrate within the lifetime of most scientific projects.

3.3 Recognize science communication as a valued professional activity

A large part of geoscience research is funded through government agencies around the world. These agencies are often funded by taxpayers, and as such, researchers have a responsibility to communicate their findings to the public. Unfortunately, few scientists around the world receive training in science communication aimed at the broader public. It should be noted that, in most parts of the world, scientists in academia do not receive training in teaching, even though they are expected to teach as part of their job responsibilities. In light of this, it is essential that clear criteria for science communication be included as part of job requirements, with room for performance review and compensation. Science communication should also be incentivized for academic promotions. This would be similar to how teaching is incentivized for promotions.

We need to emphasize the importance of giving science communication greater recognition, funding, and job opportunities. Additionally, Mulder et al. (2008) identified several steps for bringing order and appropriate recognition to the discipline of science communication: 1) Formation of a Register of Science Communication Programs; 2) Recognition of a Core Framework; 3) Establishment of a Database of Resources for Teaching; 4) Establishment of a Major Prize for Science Communication. The American Geophysical Union reorganized in 2018 and elevated a marginal group (officially a "Focus Group"), "Science and Society," to "Section" status, making members of this section eligible for society-wide awards. There was pushback on whether excellent communicators should become AGU Fellows, which led to the creation of a new Fellow-level award: the Ambassador Award. Similarly, the European Geosciences Union (EGU) has the Katia and Maurice Krafft Award, which recognizes researchers who have developed and implemented innovative and inclusive methods for engaging with and communicating a geoscience topic or event to a diverse audience. Since 2015, EGU has also awarded

Public Engagement Grants to celebrate and recognize excellent science communication in the Earth, planetary, and space sciences. In addition, the Geoscience Communication journal was partly established to recognize researchers and their science communication and public engagement research activities in the geosciences.

There is also a case made that not everyone can or should do science communication. Instead, we should support those who are good at it without making them suffer in the domain of their specialization. Irrespective of the stand of "scientists must participate in science communication" or "those who want to / are good at it should be supported", we must be cautious not to fall into the trap of forcing minoritized groups to selectively carry out this invisible work. The Social Sciences Feminist Network Research Interest Group (2017) argues that in order to address the issue of invisible labor, we need to quantify and recognize the impact of this work, which is often overlooked or undervalued. We need to make the invisible visible in the case of science communication as well and give recognition to those who contribute their energies towards it.

In addition to scientists, some universities nowadays also employ public engagement professionals, science writers, events organizers, and outreach coordinators who support and facilitate communication from scientists. These professionals play a crucial role in easing the communication burden on scientists and ensuring effective public engagement. Their contributions should also be recognized and supported within the academic structure. However, it is important to restate that our focus in this article remains on geoscientists engaging in geoscience communication.

In some countries, science communication is mandatory for scientists to ensure career progress. For example, in Italy, science communication is referred to as the "third mission." At some institutions in the U.S., faculty receive positive annual salary review "points" for outreach activities. Some faculty members have even adjusted their appointment percentages to include outreach as part of their paid job, partly because of accessible venues (e.g., "Dinosaurs and Disasters Day" at the adjacent natural history museum) and partly due to the way grants are structured in the U.S. The National Science Foundation requires outreach or another clearly defined "Broader Impact" on grant proposals. Principal Investigators can carry out "impact" activities themselves or hire education specialists or communication professionals to assist them. In Canada, where faculty performance is assessed based on annual reports, outreach (such as media interviews) is a subsection in these reports, but it is unclear to what extent it is valued compared to other contributions, such as graduating students or writing scientific papers.

While efforts by some national funding agencies to promote science communication is welcome, science communication should also be considered a discipline in itself which requires efforts, as in any other field of research. Quite often, scientists believe that participating in events for the public is enough to assure good institutional science communication. However, there are good reasons to not have all scientists participate in science communication. Incentivizing and training those scientists who are motivated to do so by a genuine interest may be a better approach. The scientific institution could take advantage of research groups in the field of science communication that are genuinely interested in identifying the most effective ways to involve the public in science.

Improving the assessment of scientific research output by funding agencies, academic institutions, and other entities has become an urgent necessity. In response, a group of scholarly journal editors and publishers convened at The American Society for Cell Biology's Annual Meeting in San Francisco in December 2012. Their objective was to create a set of recommendations, which is called the San Francisco Declaration on Research Assessment (DORA). DORA is now a global initiative that encompasses all academic disciplines (ASCB, 2012). It recognizes that scholarly output extends beyond published journal articles and encompasses other items such as preprints, datasets, software, protocols, well-trained researchers, societal outcomes, and policy changes that result from research. In

Canada, the Natural Sciences and Engineering Research Council of Canada (NSERC), in collaboration with four other Canadian research funding agencies, has endorsed this declaration.

In line with other scientific realms, science communication should establish clear norms regarding funders and partners to enhance transparency concerning potential vested interests of science communicators. This step ensures that the audience is informed of any external influences that may shape the narrative. Additionally, science communicators should clearly communicate their objectives with their audiences and obtain ethical clearances when relevant. Considering these aspects could help prevent deceptive campaigns, such as those with significant environmental impacts. Furthermore, incorporating these dimensions into the practice of science communication fosters a more transparent and ethically sound landscape, thereby enhancing the credibility and integrity of the field.

4 Final thoughts

Science communication is a vital aspect of the scientific enterprise, and it is our responsibility to communicate scientific concepts and discoveries to non-specialist audiences. However, as we shed light on the shadowlands of science communication, we also want to clarify that we do not want to discourage scientists from talking to kids, to teachers, to the public, and especially to legislators. There is a spectrum of science communication and science communicators within and outside of academia (Illingworth, 2023), and all of it plays an important role — even if not "professionalized". However, we must make clear criteria for science communication as part of job requirements, incentivize science communication for academic promotions, and support those who are good at it without making them suffer in the domain of their specialization. We must also ensure that the impact of science communication is visible and valued.

To make the broader goals discussed in this editorial more actionable for those not in direct positions of power, readers can take several initial steps:

1. Advocate for inclusive training opportunities: Encourage the integration of science communication training into professional development and academic curricula. Ensure that such training addresses diverse perspectives and includes underrepresented groups to promote equity in science communication.
2. Promote and share best practices: Share and implement effective science communication strategies within your institution and professional network. Prioritize practices that respect and value the contributions of all communicators, and address any systemic biases that might affect their involvement.
3. Support and mentor colleagues: Provide resources, constructive feedback, and mentorship to early-career colleagues interested in science communication, while recognizing that mentoring is valuable at all career stages. Foster a collaborative environment where early-career scientists can receive guidance and where more experienced colleagues can benefit from fresh perspectives and feedback. Additionally, nominate collaborators, colleagues, or employees who demonstrate excellent work in geoscience communication for recognition, awards, and prizes within their institutes or at national and international levels (e.g., conferences).
4. Engage in equitable dialogue: Initiate and participate in discussions about the importance and value of science communication. Advocate for fair recognition and compensation for science communicators, and work to build broader support within your community while being mindful of the different challenges faced by underrepresented groups.

While the case in favor of science communication has garnered significant attention in recent years, it is also essential to contemplate why not all academics should be compelled to engage in science communication. This consideration becomes especially pertinent within the context of an already exploitative environment, namely academia. Science communication, when undertaken indiscriminately, may not adhere to the same standards of honesty and rigor expected from either scientists or journalists. Additionally, it is impractical and inefficient to expect every academic to excel in all sub-specializations, encompassing research, teaching, enterprise, communication, and more.

Instead, a more equitable approach entails recognizing the intrinsic value of specialized expertise in the field of science communication and providing unwavering support to dedicated professionals in this domain, while safeguarding against exploitation and potential detriment to their long-term careers. By adopting this approach, we can contribute to a more transparent and responsible landscape within the realm of geoscience communication, effectively addressing concerns related to exploitation and the invisibilization of the invaluable contributions made by science communicators. Such efforts will ultimately preserve the credibility and efficacy of science communication, facilitating the public's enhanced understanding of scientific concepts, and thereby benefiting science, scientists, and society as a whole.

This editorial is based on a review of the literature and our own experiences, with a focus on geoscience communication. It is not a comprehensive review of the entire field of science communication. The challenges discussed are primarily informed by contexts in the Global North; however, similar shadowlands of science communication likely exist in other regions, influenced by factors such as race, gender, ethnicity, religion, language, and caste. An in-depth analysis through surveys or additional research could reveal more pervasive issues and highlight new challenges. We hope the insights shared here inspire and inform efforts to enhance fair science communication across diverse contexts and disciplines.

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