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Review article

A spectrum of geoscience communication: from dissemination to participation

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♀*Invited contribution by Sam Illingworth, recipient of the EGU Katia and Maurice Krafft Award 2023.*

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Abstract. This review article is a written contribution to accompany the 2023 Katia and Maurice Krafft Award from the European Geosciences Union. Through a consideration of my own practice and that of the wider literature, I explore how creative approaches (primarily poetry and games) can enhance the diversification of geosciences and facilitate broader engagement in its research and governance. I propose a spectrum for geoscience communication, spanning from dissemination to participation, and contend that effective communication demands a creative approach, considering the requirements of diverse audiences. I offer practical recommendations and tactics for successful geoscience communication, including audience awareness, transparency, and engagement with varied communities. This article emphasises the significance of fostering increased recognition for science communication within geosciences and promoting wider engagement in its research and governance. It delivers valuable insights for researchers, educators, communicators, and policymakers interested in enhancing their communication skills and connecting with diverse audiences in the geoscience domain.

1 Introduction

In 2023 I was awarded the Katia and Maurice Krafft Award from the European Geosciences Union (EGU). This award, named in honour of the volcanologists Katia and Maurice Krafft (Calderazzo, 1997), recognises researchers who have developed and implemented innovative and inclusive methods for engaging with and communicating a geoscience topic or event with a diverse audience. As part of this award, I was invited to give a lecture at the 2023 EGU General Assembly (which can be viewed in full here: https://www.egu.eu/awards-medals/katia-and-maurice-krafft-award/2023/sam-illingworth/, last access: 30 October 2023) and to also provide a written contribution, based on this lecture, to one of the EGU journals. Given that a large part of my award and subsequent lecture was grounded in the work that I have done since helping to found *Geoscience Communication* in 2018, it seemed as though this would be the most appropriate place for such an article.

The purpose of my lecture, and hence this article, is to attempt to provide a review of the potential of creative approaches in geoscience communication and a discussion of the possibilities for future work, with recommendations based on both my own practice and the wider literature. In attempting such an exploration, I would first like to introduce the concept of a spectrum for geoscience communication.

I have written elsewhere (Illingworth, 2022; Illingworth and Allen, 2020) about the need for inward-facing and outward-facing science communication – that there is a need for science to be inwardly communicated to other scientists (e.g. via peer-reviewed research articles and conference presentations) and a need for science to be outwardly communicated with non-scientists (e.g. via policy documents, radio programmes, and collaborative workshops). In developing this argument, I would like to present this outward-facing side of science communication, and hence geoscience communication, as existing on a spectrum, with dissemination at one end and participation at the other (see Fig. 1).

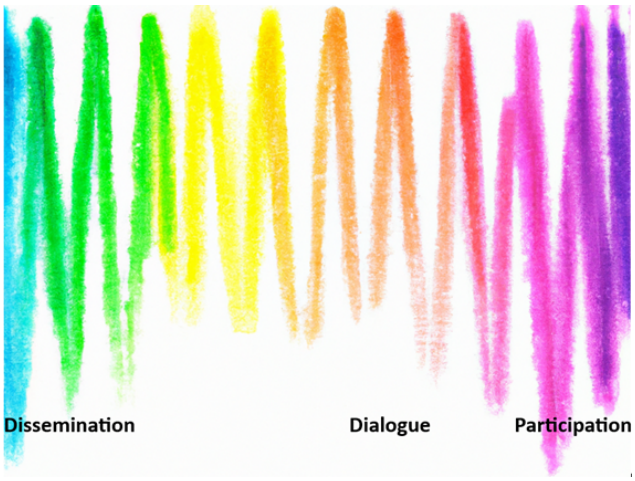

Figure 1. The spectrum of geoscience communication, from dissemination to participation (image created using the generative artificial intelligence tool DALL-E with the prompt "the electromagnetic spectrum as a watercolour").

Although many might consider participation and dialogue to be the ideal approach for science communication, some goals may be better achieved through dissemination. For example, science documentaries, whilst unidirectional from scientific to non-scientific publics, have been shown to potentially have an impact at a wider societal level (Dunn et al., 2020). Likewise, providing accurate and easily understandable information is often a crucial prerequisite for initiating dialogue and, with it, participation (Resnik et al., 2015).

In other words, Fig. 1 is not a hierarchical spectrum but rather a tool to help identify the form of a particular geoscience communication initiative. In doing so, it is first necessary to consider both the aims of the initiative and the needs of the audiences. For example, if you are interested in developing relationships with local communities and decision makers to reduce negative volcanic impacts and uncertainty (Marin et al., 2020), then you would likely need to engage in some form of dialogue. Similarly, if you are aiming to engage multiple publics to recover old records of sub-daily weather observations at sea in order to make them useable in current climate models (Hawkins et al., 2019), then a more participatory approach would be appropriate.

It is important to recognise that there is not a single "general public". Instead, multiple publics exist, each with their unique challenges and possibilities for engagement, as well as their own motivations for engaging (or not) with science (Illingworth and Wake, 2021). When deciding which public to engage with, it is therefore essential to carefully consider what and why you want to communicate, as well as the reasons for interacting with your chosen audience.

In utilising this spectrum for geoscience communication, I also propose that a creative approach is effective for several reasons. Creative methods simplify complex concepts by employing techniques such as storytelling, analogies, and visualisation, making the subject matter more accessible to non-experts (Schäfer and Kieslinger, 2016). They also enhance retention as entertaining and emotionally engaging content is often more memorable (Wilkinson and Weitkamp, 2020), and they facilitate dialogue and interaction between geoscientists and non-geoscientists, promoting collaborative learning experiences (Illingworth, 2020a). Additionally, a creative approach has been shown to foster interdisciplinary collaboration between geoscientists and professionals from other disciplines, such as artists, educators, and communicators, leading to innovative ways of presenting geoscience information and reaching broader audiences (Illingworth, 2022).

I will spend the remainder of this article investigating the three distinct sections of this spectrum: dissemination, dialogue, and participation, outlining examples of effective practices for each using creative methodologies. In doing so, I will present an overview of my research into using poetry and analogue games as facilitatory media to help disseminate knowledge, develop dialogue between scientists and non-scientists, and engender participation amongst diverse publics, including those audiences that have previously been marginalised by the geosciences, for example communities of colour, persons with disabilities, and individuals from lower socioeconomic backgrounds (Hall et al., 2022).

In addition to my own research, I will also explore how the work that we are doing with *Geoscience Communication* is supporting others in developing innovative and effective research and practices in this space and how this, in turn, is helping to provide greater recognition for science communication in the geosciences. In doing so, I hope to outline what makes for effective geoscience communication and why I propose that a creative approach is one way in which we might do this.

2 Dissemination

Geoscience research can be complex and technical, making it difficult for non-specialists to understand and appreciate its significance. However, by using poetry as a means of science communication, geoscientists can convey their research in a more accessible and engaging way (Young and Kulnieks, 2022). Poetry can help to simplify complex scientific concepts and make them more relatable to a wider audience (Wardle and Illingworth, 2022). For example, a poem about the impact of climate change on glaciers could use vivid imagery and metaphors to convey the beauty and fragility of these natural wonders while also highlighting the urgent need for action to address climate change (Illingworth, 2016).

In addition to making geoscience research more accessible, poetry can also help to create emotional connections with readers or listeners. By evoking emotions such as wonder, awe, or concern, poetry can inspire people to care about geoscience issues and take action to address them. This is par-

ticularly important when it comes to issues such as the climate crisis or disasters, which can often feel overwhelming or abstract (Illingworth, 2020b). Poetry can help to humanise these issues and make them more tangible (Anabaraonye et al., 2018). The following poem is an example of how poetry might be used to disseminate key geoscientific topics to non-scientific audiences. This poem is inspired by the work of Ma et al. (2023), which has found that, while air pollution has decreased across the United States, health burdens remain unequal among racial groups.

Death's Dirty Hands

Smog's spectre looms,
choking the throats
of the innocent –
charcoal fingers clutching
at fragile hearts.
The fumes of progress
do not discriminate,
and yet
they weigh heavier
on some.
Gasping for breath,
the afflicted cry out –
their wheezing laments
suffocated in the haze.
Poisonous clouds
begin to shift,
their ashen grasp
slowly released.
Yet many remain,
trapped
in a tainted embrace –
how long
must they wait.

Figure 2. Participants of the EGU General Assembly 2018 play-testing an early version of the Catan®: Global Warming game.

Like poetry, analogue games are effective at disseminating geoscientific research to a non-specialist audience for a variety of reasons. In using the phrase analogue game, I mean any non-digital game that can be played on a table (e.g. card, dice, and board games). When it comes to geoscience communication, the advantages of analogue games, compared to their digital alternatives, may encompass factors such as cost (regarding development, technology, and resources); adaptability (allowing players or educators to effortlessly modify game parameters to align with their educational objectives, time, and space constraints); and, most notably, the manner of engagement, which typically involves direct player interaction (Illingworth and Wake, 2019).

Analogue games inherently engage participants through their interactive and entertaining nature, making participants more likely to retain information and maintain interest in the topic (Pfirman et al., 2021). Such games are also a helpful medium for simplifying complex concepts; they have the capacity to break down unfamiliar geoscientific ideas into more manageable elements (Fjællingsdal and Klöckner, 2020), making them accessible and understandable to non-specialists (Locritani et al., 2020). Finally, analogue games encourage active learning (i.e. engaging people directly for deeper comprehension and retention) as players must apply their knowledge and problem-solving skills to progress; this hands-on approach can promote a deeper understanding and greater retention of geoscientific concepts and hone a wide range of transferable skills (Martindale and Weiss, 2020; Pfirman et al., 2021). Figures 2 and 3 show early prototypes of two such games being play-tested at the EGU General Assembly in 2018 and 2019, respectively.

Other creative media that have proven to be effective at disseminating geoscientific research to non-specialist audiences include music (Menghini et al., 2020), comics (Wings

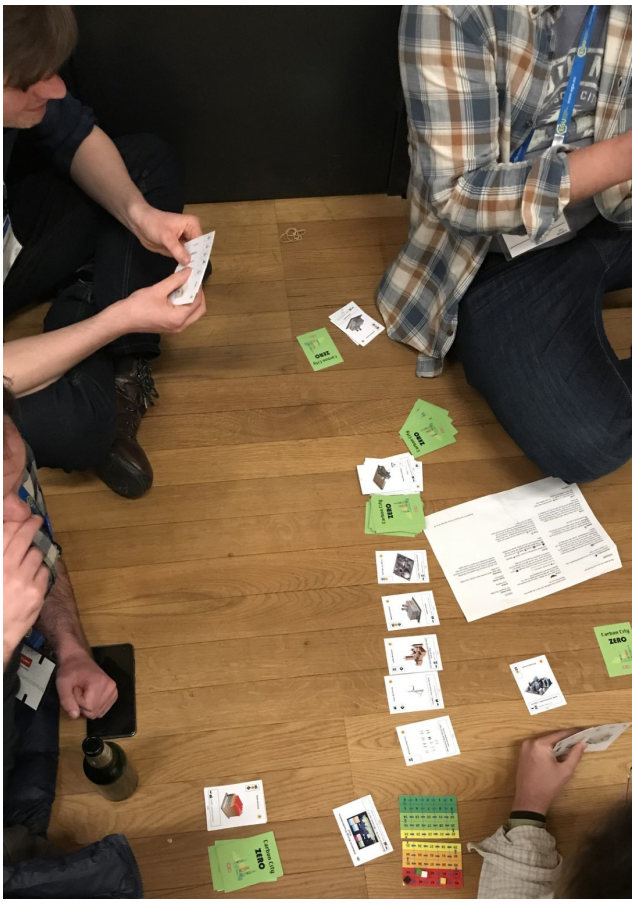

Figure 3. Participants of the EGU General Assembly 2019 playtesting an early version of the Carbon City Zero game.

et al., 2023), and even letter writing (Stiller-Reeve et al., 2023). Likewise, there are many examples of digital games being used as an impactful (and equally effective) tool for dissemination. This has perhaps proven to be most successful when researchers have used well-known, video game franchises such as Minecraft (Rader et al., 2021), Monster Hunter (McGowan and Scarlett, 2021), Pokémon (McGowan and Alcott, 2022), and Zelda (Hut et al., 2019) to explore how the geosciences are represented (or not) in these game worlds.

3 Dialogue

Whilst poetry and analogue games are effective media for disseminating geoscientific research from scientists to non-scientists (Fung et al., 2015; Illingworth, 2020b), their real strengths lie in the capacity to facilitate dialogue between these publics.

To genuinely advance scientific research and discourse, it is essential to address our social responsibility as scientists and make science accessible to everyone rather than an exclusive privilege for a select few. Engaging diverse publics in a genuine two-way conversation about our research, its relevance to them, and the potential contributions they can make to new knowledge is crucial. By not establishing this dialogue, we miss the opportunity to benefit from the expertise of the publics we aim to communicate with. These publics, although not scientists, possess expertise in various aspects of their personal and professional lives. By seeking their opinions and identifying ways to benefit from their knowledge, we (as geoscientists) can therefore enhance our own understanding and knowledge.

One of the main challenges in creating such two-way conversation is the presumption that geoscientists are experts, while others are not. This can make people feel less important and less likely to share their thoughts, even though they might have valuable insights about a topic and how it affects society. These obstacles, known as hierarchies of intellect (Illingworth and Jack, 2018), emerge when people are urged to discuss a subject where one party (i.e. the geoscientist) is perceived as an expert, while the other (i.e. the other publics) is not. Such hierarchies hinder effective dialogue and can lead to marginalising audiences, discouraging them from sharing their knowledge and experiences. Yet these insights might be necessary for a better understanding of specific research findings and their potential implications for the broader society.

One way to break down these barriers is by writing and sharing poetry together in a friendly and supportive setting. This helps create a safe space for dialogue and experimentation, levelling hierarchies and allowing for a true exchange of ideas between different groups, each with their own knowledge and experiences (Illingworth and Jack, 2018; Illingworth et al., 2018). Collaborative poetry sessions are successful in creating dialogue for three reasons: they show the public that their expertise is valued, they allow scientists to connect with people on an emotional level, and they create a sense of shared vulnerability (Illingworth, 2020a).

These collaborative poetry-writing sessions are especially effective when engaging with audiences who have traditionally been under-served or marginalised by the geosciences. For example, my own work has shown how poetry can help to engage potentially vulnerable audiences with both the climate crisis (Illingworth et al., 2018) and environmental change (Illingworth and Jack, 2018) more broadly in a supportive, constructive, and safe environment. Similarly, other studies have shown how poetry can be used to develop dialogue between geoscientists and non-scientists on topics ranging from soil (Maria and Arnalds, 2018) to the conservation of natural heritage (Nesci and Valentini, 2020).

Similarly, analogue games provide a way of developing these two-way dialogues, mostly because of something that is referred to in game studies parlance as “the magic circle” (Stenros, 2014). This circle refers to the imaginary boundary that separates the game world from reality. Within this circle, players engage in activities governed by specific rules and structures, suspending real-world norms and embracing the game’s own reality. This suspension allows us to move be-

yond any hierarchies that may exist outside the gaming context, enabling interactions that might not be possible otherwise (Illingworth and Wake, 2021). For instance, in the board game Monopoly, it is acceptable (if not essential) behaviour to try and bankrupt your fellow players by levying rental income on multiple properties, behaviour that (one would hope) is viewed as being morally repugnant away from the gaming table. Agreeing to abide by a set of purposeful, albeit sometimes restrictive, rules can help create a secure environment for fostering new interactions and learning. Doing so helps to break, or at least temporarily suspend, any hierarchies of intellect, allowing for more inclusive engagement and rich dialogues to emerge.

One example of such a game that does this from a geoscientific point of view is Keep Cool, a climate negotiation game in which players assume the roles of countries or nations, each with distinct economic interests, objectives, and capabilities (Fjællingsdal and Klöckner, 2020). The actions players take to achieve their goals also generate greenhouse gases, and everyone loses if the global temperature rises too much (Fennewald and Kievit-Kylar, 2013). Each round, players must decide whether to implement climate protection measures that benefit all or act in their self-interest to reach their goals more quickly. The first player to achieve their goal wins, but a total lack of cooperation among players can lead to global environmental collapse. This game creates a neutral environment where scientists and non-scientists can interact on equal footing, breaking down barriers and enabling open dialogue. Similarly, by taking on the roles of different countries with varying interests, players gain insight into the diverse perspectives and challenges faced in real-world climate negotiations, fostering empathy and understanding between scientists and non-scientists.

Likewise, when we designed our Global Warming expansion (see Fig. 2) for the popular analogue game Catan® (Illingworth and Wake, 2019), we wanted to create a game (or in this case, a modification for an existing game) that enabled geoscientific and non-geoscientific publics to explore the consequences of individual action and the extent to which mitigating the negative effects of global warming requires a collective response.

During the game's play-testing, feedback from various play-testers suggested that the game mechanics, rather than any related story, effectively fostered dialogue on a specific subject, such as global warming. This game was play-tested with 105 players, of whom 65 participated in formal post-game surveys. The initial play-testing undertaken with friends and colleagues did not involve formal surveys; instead, we asked informal questions on gameplay and mechanics, using responses to further develop the game. In subsequent play-tests, players completed a survey via Google Forms, which outlined the study and purpose of collecting feedback. In some cases, paper copies were provided, with the authors manually inputting play-tester responses into Google Forms (see Illingworth and Wake, 2019, for a copy of the survey form that was used in this study).

In analysing this feedback, we also concluded that, to develop an analogue game for effective dialogue, it is essential to consider the game's accessibility, players' game literacy, the peer review of scientific content, and the degree to which the meta-game (i.e. discussions occurring around and beyond the game) is facilitated.

As with dissemination, many other creative forms of geoscience communication have also been used to foster effective dialogue between geoscientists and non-geoscientists. Such initiatives have included films (Archer, 2020), sculptural work (Lancaster and Waldron, 2020), and print making (Macklin and Macklin, 2019). What arguably marks these initiatives as being especially effective is that they have led to actionable dialogue for the publics involved rather than just the creation of another "talking shop" for researchers to share the "brilliance" of their geoscientific findings. Such actions include supporting film makers in their integration of space science, influencing social policymaking, and inviting artists to reflect on the impact of catastrophic natural events on both their communities and themselves.

4 Participation

There are two phrases that often get bandied around in public engagement and science communication parlance when it comes to participation: citizen science and co-creation.

Citizen science projects in geosciences, such as those geared towards disaster risk reduction (Hicks et al., 2019), have the potential to both benefit multiple publics and also utilise the lived experience and expertise of non-geoscientists in a tangible and actionable manner. However, concerns arise regarding the potential exploitation of participants as free labour, with scientists reaping the benefits and recognition (Strasser et al., 2019). To address this, it is essential to actively involve participants and acknowledge their contributions, ensuring they are not treated as second-class citizens. Embracing social media and communication platforms can further expand engagement in citizen science projects while promoting fair recognition for all involved (Liberatore et al., 2018). Similarly, creative media such as art and poetry provide a powerful medium through which to challenge and address some of these potential inequities (see e.g. Bauman and Briggs, 2003; Torre and Fine, 2011).

Another issue with citizen science is that some form of training is often essential. Simpler tasks demand minimal training, while more complex ones require extensive instruction. To encourage participation, most projects aim for low training requirements. Nonetheless, adequate training is needed to maintain data quality. Again, this is where creative methodologies can help to contribute to the field, with music (Oliver et al., 2021) and games (Strobl et al., 2020) both hav-

ing been shown to be effective (and fun!) ways of providing training in an equitable and effective manner.

Similarly, co-creation is a participation phrase that is often used, yet perhaps with more fervour than is strictly true or necessary. An example of meaningful co-creation would be a team of geoscientists partnering with an indigenous community to study climate impacts on local ecology. The collaboration would begin by asking community leaders to shape the research goals based on their priorities, with community members trained to conduct field measurements and interpret findings. All involved would be reminded of the need for any climate adaptation strategies to be firmly grounded in indigenous knowledge, with any study results co-published to uplift the community's voice.

Likewise, a more surface-level approach might involve a group of geoscientists inviting some local high school students to participate in an ongoing climate change study. Students would be given pre-defined research tasks like data entry and basic sample processing, with limited influence on the study design or goals. Most data interpretation and all major decisions would remain with the lead scientists, with students being recognised in acknowledgements but not credited as co-authors on any published findings.

In the first example, the hypothetical community played an active steering role at all stages, and the project design was shaped by their goals and perspectives. In the second, students had limited influence on key decisions, with the power dynamic skewed towards the scientists' leadership. In true co-creation, collaborations should start early, involving all participants from the beginning to maximise skill and expertise benefits (Illingworth, 2022). Including all collaborators in formulating research questions and aims promotes trust and teamwork and fosters innovative ideas, enriching the experience for everyone.

A creative example of a genuinely co-creative process is the poetry and art journal that I help to curate. *Consilience* (https://www.consilience-journal.com/, last access: 30 October 2023) is the world's first peer-reviewed science and poetry journal, publishing themed poems and artwork by creatives from all backgrounds. The journal provides support to develop the craft and identity of contributors, using a peer-review system like scientific journals. *Consilience* is run by over 80 global volunteers and has around 8000 monthly readers. The journal was created to help develop the work of others in the field, transcending individual limitations. Early collaborators defined the journal's purpose, framework, and submission process.

Consilience is a good example of an interdisciplinary collaboration between scientists, poets, and other creatives, where the co-creation began at the very start of the project and through which multiple voices were both present and platformed. However, whilst the journal is clearly doing good work in helping to diversify the ways in which science is interrogated and communicated, it is not engaged with the creation of geoscientific research itself (at least not directly). This is where analogue games come in.

The process of designing analogue games offers an immersive approach to co-creation in the geosciences, the reason being that designing, play-testing, and debriefing games is a genuinely collaborative method that involves listening to several different voices and then reflecting and acting on these suggestions for input and development.

In 2018, my colleague, Paul Wake, and I collaborated with the climate charity Possible to develop workshops exploring heat decarbonisation and the UK's transition to a zero-carbon economy (Rydge et al., 2018). Utilising games as icebreakers and tools to generate dialogue, we engaged multiple publics, including climate activists, policymakers, educators, journalists, students, researchers, and industry professionals. These workshops were designed to gather knowledge from a variety of communities who all had an interest and expertise in the subject. This knowledge was collected via participant observation and written responses to questions, which were then used to create the framework for a card game.

Following an initial design phase, the card game was then play-tested with other members of the same (and similar) communities (see Fig. 3), with their feedback used to improve the game in terms of both its narrative and mechanics. The final game, Carbon City Zero, involved players taking on the role of city mayors and competing against one another to become the world's first zero-carbon city (Germaine, 2022). The game was made available to download as a free print and play, and a physical copy of the game was also successfully launched on the crowd-funding platform Kickstarter.

Following the release of Carbon City Zero, further members of the various communities that had been involved in the research project got in touch with their own feedback. Most of this feedback was centred around one key issue: why was the game competitive when, for a truly zero-carbon world, cities should be working collaboratively. As a result of this feedback, a second edition of the game was collaboratively developed and released as Carbon City Zero: World Edition (Illingworth and Wake, 2021). In this version of the game, players had to work collaboratively to reduce the carbon level of a single city to zero within a strict time limit. Players then either collaboratively won or lost together. As game designers and researchers, we found this to be a useful example of why one should really listen to the needs of the various publics you engage with rather than just assume what they want.

Overall, this project successfully involved diverse communities, valued their opinions, and used their expertise to improve the game. Conversely, there were areas for improvement. Workshop attendees generally shared similar views on a zero-carbon future so including dissenting or differently informed voices could have highlighted more barriers to reducing carbon emissions and fostering dialogue on the topic.

From the feedback that we received following the release of the game, we know that it has been used as a tool for enact-

ing actual change, e.g. by town hall planners to discuss issues of net-zero policies with their fellow councillors, as well as in multiple grant applications for similar games-based geoscientific research. However, there are even more effective examples from across *Geoscience Communication* that have used creative methodologies to develop co-creative partnerships between geoscientists and other publics. This includes using storytelling to co-create interventions addressing the climate crisis (Woodley et al., 2022), using science theatre to debunk scientific mistruths (França et al., 2021), and even a meta-analysis of creative practice as a tool to build resilience to natural hazards in the Global South (Van Loon et al., 2020).

5 Conclusions

By providing examples from my own research and practice, alongside other peer-reviewed and highly impactful examples from the wider literature, I have demonstrated the potential of creative approaches in geoscience communication. However, creative approaches may not always be feasible or appropriate for every situation. For instance, in cases where conveying highly technical information is required, an alternative approach might be better suited to ensure accuracy and clarity. Additionally, certain creative methods might not resonate with all audience members; therefore, it is essential to consider a wide range of strategies to maximise engagement.

To address these limitations and develop effective communication strategies with various publics, here are five recommendations for geoscientists to consider when looking to develop their own effective geoscience communication strategies:

1. Know your audience. Before communicating any scientific information, you should understand who your audience is and what their interests and needs are. This will help you tailor your message and delivery to be more effective. And remember, there is no such thing as the general public.

2. Be adaptable. Recognise that different situations and audiences may require different communication approaches. Be prepared to adjust your strategy as needed to best engage your audience. Use the spectrum of geoscience communication (Fig. 1) to determine the most appropriate method to achieve your aim with your intended audience.

3. Be creative. Embrace creative methodologies when appropriate to make your communication more engaging and relatable. This may include poetry, storytelling, art, games, or other interactive methods.

4. Be transparent. When communicating scientific information, you need to be transparent about any uncertainties or limitations in the data or research. This helps build trust with your audience and promotes open dialogue.

5. Engage with diverse communities. To promote greater recognition for science communication in the geosciences, engage with diverse communities and promote inclusivity in all aspects of research and practice.

By following these recommendations, geoscientists can develop effective communication strategies that engage diverse audiences and promote greater recognition for science communication in the geosciences. Embracing creativity and inclusivity will not only enhance the field of geoscience communication but also help address global challenges by fostering collaboration and understanding across disciplines and communities.

Data availability. No data sets were used in this article.

Competing interests. The author is a member of the editorial board of *Geoscience Communication*. The peer-review process was guided by an independent editor, and the author also has no other competing interests to declare.

Ethical statement. As the author of this article, I have made every effort to ensure that the research and practices discussed in this paper adhere to the highest ethical standards. All studies and projects mentioned were conducted in accordance with relevant institutional and national guidelines, with the necessary approvals and informed consent from participants when applicable.

I have taken care to provide accurate, balanced, and transparent information, as well as to acknowledge the limitations and challenges of the methods and approaches discussed. I have also been conscientious about giving proper credit to the work of other researchers and creatives, with appropriate citations and acknowledgements.

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