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Profiling the geoscience community: exploring patterns of science communication and public engagement

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Abstract

This research investigates how members of the geoscience community in Portugal perceive and engage in science communication, identifying distinct patterns and practitioner profiles. Statistical analysis and a clustering algorithm were used to identify communication patterns based on practitioners' communication goals, target audiences, training, and self-efficacy. The results align with expected patterns, but provide new empirical evidence of the relationship between communication goals and audience targeting, offering specific data for the geoscience community.

Keywords

Science communication: theory and models; Professionalism, professional development and training in science communication

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1 ▪ Introduction

A large and growing body of research focuses on the importance of public engagement and effective strategies for science communication [e.g., Besley & Dudo, 2022; Bucchi & Trench, 2021; Gascoigne et al., 2020]. Along with the growing recognition of the importance of science communication comes increasing support for efforts to engage the public with science from governments, scientific institutions, and other stakeholders. This means that the quality and efficacy of scientists' communication is more crucial than ever. Institutions that promote effective science communication practices must understand that science communication practitioners form a heterogeneous group, each with unique needs [Jensen, 2011]. By adapting support to meet the diverse needs of different segments within the science communication community, more impactful and positive outcomes can be achieved.

Previous studies have shown that academic models of science communication do not necessarily reflect science communication professionals' practices [e.g., Davies, 2021; Gerber et al., 2020; Kahan, 2013; Miller, 2008; Priest, 2010].

Additionally, the underrepresentation of practitioners' perspectives in the science communication literature [Salmon & Roop, 2019] highlights the call for greater collaboration between researchers and practitioners, such as through training, to achieve better outcomes [Han & Stenhouse, 2015; Jensen & Gerber, 2020; Riedlinger et al., 2019; Salmon & Roop, 2019; Seethaler et al., 2019].

Research has highlighted that researchers' support needs are influenced by the disciplinary communities they belong to [Costa e Silva & Pinto, 2023; Costa e Silva et al., 2024], with studies focused on specific scientific communities such as astronomy, nano-science or climate science [Anjos et al., 2021; Corley et al., 2011; Entradas et al., 2019]. Nevertheless, few studies have specifically focused on the geoscience community [Liverman & Jaramillo, 2011; Rodrigues, Castro et al., 2023].

Despite having a significant impact on the daily lives of citizens, geosciences suffer from a general lack of visibility [Brilha, 2004; Stewart & Nield, 2013]. Geoscientists work mainly behind the scenes, although they play vital roles in numerous areas. They ensure water availability and quality, safeguarding clean water supplies. They assess and mitigate geological hazards, enhancing public safety. They manage land and the environment, promoting sustainable resource use and conservation. They tackle environmental issues like soil degradation, affecting agriculture. They aid urban planning by considering geological factors for resilient cities. They also contribute to understanding and mitigating climate change impacts.

Moreover, the geoscience community plays a crucial role in meeting society's escalating demand for both mineral and energy resources, leading efforts in exploring, extracting, and managing these essential materials, while striving to develop innovative and environmentally conscious approaches, contributing not only to the responsible use of mineral resources but also to the ongoing global energy transition. Science communication is thus a major concern in terms of improving the dialogue between this specific scientific field and society, to promote safer and better living conditions.

Notwithstanding this importance to society in general, a collective identity for the geoscience community cannot be presumed. This community is constituted by professionals who share a common scientific field but who also have different intentions when communicating science and address various types of audiences. Thus, within the community, different profiles can be expected. Identifying profiles enables more targeted and effective responses to specific needs, such as addressing continuing professional development, as has been extensively shown in the case of teachers [de Vries et al., 2013; Vermunt & Endedijk, 2011]. By understanding the unique characteristics, skills, and needs of different groups, tailored strategies can be developed, ensuring that development efforts are more relevant and impactful, ultimately leading to better outcomes. This is also true when considering the impact of training that can be more effective if tailored to different needs.

Studies on patterns of third mission engagement among scientists and engineers in academia have also identified several distinct profiles, including factors like science communication alongside other key variables [Mejlgaard & Ryan, 2017]. The identification of patterns among scientists on Twitter has, for example, advanced knowledge of science communication on social media and provided valuable insights for developing and using concrete metrics [Ke et al., 2017].

In addition, clusters provide evidence of systematic differences between groups. To effectively understand and address specific challenges, it is essential to analyze these differences across particular dimensions [Pedder, 2007]. From a different perspective, cluster analysis can offer theoretical contributions to theory development and contextual understanding, supporting future research, while also providing practical contributions through tailored activities and strategic planning [Uwizeyemungu et al., 2020].

Clustering methods are highly useful in marketing and service management for customer segmentation, such as segmenting customers for targeted product recommendations on e-commerce platforms [Gaikwad & Lamkuche, 2021] or analyzing energy consumption profiles [Henriques et al., 2024] to tailor marketing strategies and optimize service offerings. By applying clustering techniques, businesses can better understand customer behavior, anticipate needs, and create personalized experiences, the same way that identifying patterns in science communicators enables more tailored approaches for effective engagement.

The present study deepens the research about the Portuguese geoscience community regarding public engagement [Rodrigues, Castro et al., 2023]. The results will contribute to the development of a framework for geoscience communication, addressing specific needs, and providing clues for institutions and policymakers, to overcome the constraints and contribute to more effective communication. By empirically identifying distinct communication profiles, the study aims to enhance understanding of the geoscience community's approaches to public engagement.

Besley and Dudo [2022] distinguish 'goals' from 'objectives', with 'goals' referring to the overarching purposes or long-term aims that science communicators strive to achieve, while 'objectives' are the specific actions or steps taken to reach those broader goals. In this study, we have widely referred to the intended outcomes as 'goals', as they represent broader, over-arching aspirations of members of the geoscience community in their communication efforts.

Understanding the profiles of communicators enables the development of better and targeted approaches, optimizing strategies and promoting more effective and fruitful engagement with society.

2 ▪ Background

Previous studies have identified several predictors of public engagement, including demographic factors (like disciplinary background), personal motivations (such as self-efficacy), as well as institutional factors [e.g., Besley et al., 2013; Jensen, 2011; Poliakoff & Webb, 2007]. Specifically within the geosciences community, factors like professional experience, institutional recognition, financial support, personal satisfaction, and expertise have been identified as influencing public engagement [Rodrigues, Castro et al., 2023].

2.1 ▪ *Science communication approaches*

To understand science communication approaches, practices and their theoretical context within the prevalent models — dissemination, dialogue, and participation [Trench, 2008] it is important to reflect not only on the practices and tools themselves but also on the goals and their target audience: who they are and how they are perceived [Besley et al., 2019].

As the field has evolved, science communication paradigms have shifted from deficit models focused on correcting public misconceptions to dialogue models emphasizing two-way communication and public engagement, and now to participatory models that foster collaboration and co-creation of knowledge, empowering society [Bauer et al., 2007; Bucchi & Trench, 2021; Davies, 2021].

The roots of dissemination approaches to address knowledge deficits stem from scientists' traditional view that public mistrust, tensions, or misinformation are due to knowledge deficits, driving their efforts to 'inform' and 'educate' [Dudo & Besley, 2016; Ridgway et al., 2020; Royal Society, 2006]. The belief is that the public is willing and able to process and understand scientific information, which assumes a linear correlation between knowledge and attitudes. Evidence suggests otherwise [Light et al., 2022; Rabb et al., 2019]. Viewing audiences as uniform, passive and influential, scientists expect that providing accurate information will shift attitudes and increase interest, interpreting any obstacle as a knowledge gap [Bauer et al., 2007; Bauer, 2009; Besley & Nisbet, 2013; Trench, 2008]. This assumption is evident in the long-standing prevalence of public lectures, a linear model where speakers convey information to passive audiences as a key form of engagement [e.g., Liverman & Jaramillo, 2011; Royal Society, 2006].

However, the advances and challenges posed by the planet, science, and technology have necessitated new forms of engagement. Scientists are increasingly required to participate in dialogue, consultation, negotiation, and co-creation activities [Bucchi & Trench, 2021].

Comparing different fields, social scientists tend to emphasize civic engagement, while natural scientists on education [Entradas & Bauer, 2017], highlighting a differing understanding of communication purposes.

Given the nature and impact of their work, members of the geoscience community are diversifying their audiences and strategies by increasingly engaging with policymakers, politicians, and NGOs, a process that requires dialogic and participatory approaches but clearly presents challenges [Liverman & Jaramillo, 2011; Rodrigues, Costa e Silva & Pereira, 2023; Stewart, 2024; Stewart & Nield, 2013]. However, few scientists see themselves as facilitators of public participation in decision-making [Besley & Nisbet, 2013], highlighting a gap between their engagement efforts and their perceived role in the process.

There are numerous goals and objectives that guide efforts, providing direction and purpose for science communication and public engagement [Besley & Dudo, 2022; Metcalfe, 2019; Scheufele et al., 2021]. These range reflect distinct approaches within the three paradigms, illustrating the relationships between scientists and the public and also offering insights into the interplay between theory and practice [Metcalfe, 2019; Zimmerman et al., 2024].

2.2 ▪ *Training and self-perceived competence*

Scientists are increasingly motivated to communicate science but often lack effective skills [Dudo et al., 2021], relying on personal instinct and experiences [Salmon & Roop, 2019]. While science communication training is sparse in undergraduate courses, workshops and training programs are growing [e.g., Bankston & McDowell, 2018; Baram-Tsabari & Lewenstein, 2017; Greer et al., 2018; Longnecker & Gondwe, 2014; Miller et al., 2009; Mulder et al., 2008].

Literature reveals that scientists who participate in training are more likely to engage with publics, feel confident and enjoy their public engagement experiences [Parrella et al., 2022; Royal Society, 2006; Silva & Bultitude, 2009].

Scientific institutions often provide capacity building and encourage training, while scientists also seek training independently to enhance their public communication [Besley et al., 2015], especially looking to improve technical skills related to language and messages [Altman et al., 2020].

Reviews on training programs show a range of formats and goals [Besley et al., 2015; Mulder et al., 2008; Newman, 2019; Yuan et al., 2017].

Several authors advocate for training in dialogue and participation strategies [Anjos et al., 2021; Dudo et al., 2021; Miller et al., 2009; Stewart, 2024; Trench & Miller, 2012], emphasizing both theoretical models [Rose et al., 2020; Simis et al., 2016], and creating direct interactions between scientists and audiences [Besley & Tanner, 2011; Bubela et al., 2009]. Trainers recognize the value in building two-way communication skills, but implementation remains limited and inconsistent [Yuan et al., 2017].

Effective training programs should be tailored to address specific contexts like academia, policymakers, funders, or industry, and their impact should be evaluated [Baram-Tsabari & Lewenstein, 2017; Bankston & McDowell, 2018; Rodgers et al., 2020]. Acknowledging values [Seethaler et al., 2019], understanding audiences [Bray et al., 2012; Dudo et al., 2021], navigating decision-making complexities [Seethaler et al., 2019], promoting positive scientist attitudes toward engagement [Parrella et al., 2022], and fostering dialogue [Dudo et al., 2021] are relevant aspirations.

Training needs are further shaped by the cultures of different scientific disciplines [Costa e Silva et al., 2024]. In geoscience, the lack of public engagement and media training in general education highlights a gap that should be addressed in university curricula [Ickert & Stewart, 2016; Liverman & Jaramillo, 2011]. Furthermore, a study on a geoscience department found that inadequate formal training contributes to weak institutionalization and ineffective science communication policies [Anzolini, 2022].

Beyond training, personal skills and self-efficacy perception must also be acknowledged. Lack of communication skills and training is often considered a significant obstacle to effective public communication [Poliakoff & Webb, 2007], despite studies showing the opposite may also occur [Ridgway et al., 2020]. Training has been associated with higher perceived self-efficacy, meaning that those who receive it are more likely to do public engagement [Copple et al., 2020; Costa e Silva et al., 2024].

Scientists' perception of their own skills is closely linked to public engagement [Besley et al., 2013], with self-perceived competence significantly impacting both their willingness to communicate and their performance [Dunwoody et al., 2009; Poliakoff & Webb, 2007; Rodrigues, Castro et al., 2023], meaning that scientists are more likely to engage when they feel they have the necessary skills.

Studies show that scientists generally feel prepared to communicate [Rodrigues, Castro et al., 2023; Royal Society, 2006], but are sometimes overconfident [Rose et al., 2020], which can lead to underestimating the challenges of effective communication.

Also, geoscience communication training should encourage strategies that rethink practices [Ickert & Stewart, 2016] especially for members of the geoscience community handling hazards who need specialized training in risk and uncertainty [Liverman, 2009; Stewart, 2024], as seen in the positive outcomes among graduate students [Dohaney et al., 2015].

Overall, this study aims to improve understanding of the geoscience community's communication approaches and the existence of distinct communication profiles within the field. The primary objective is to empirically identify these profiles, guided by the following research questions (RQ):

RQ1 — How are the geoscience community's communication goals, practices and target audiences aligned with the science communication models?

The objective is to understand the connection between approaches and the theoretical frameworks behind them, such as the deficit, dialogue, or participatory paradigms.

RQ2 — How can members of the geoscience community be grouped based on their science communication goals and target audiences?

The objective is to identify patterns based on their communication goals, the specific outcomes they aim to achieve that definitively influence their approach, and the specific audiences they target.

RQ3 — What associations exist between training, self-efficacy and communication practices and how do these factors combine to shape communication profiles within the geoscience community?

The aim is to explore the associations between training, self-efficacy, and communication practices, while identifying distinct communication profiles within the geoscience community using a clustering algorithm

3 ▪ Methods

3.1 ▪ *Data collection*

Data were collected through a survey conducted within the Portuguese geoscience community in 2020. A self-administered online questionnaire was created using Google

Forms and distributed via email and social media (see Supplementary material A). It collected 161 indicators on demographics, practices, and representations on science communication, with this study analyzing 60 of these. A previous study on this data analyzed the views of the geoscience community, predicting willingness to communicate [Rodrigues, Castro et al., 2023].

3.1.1 ▪ *Data set*

The sample from the geoscience community extends beyond researchers and academia to include technical professionals, teachers, postgraduate students, and science communicators working in Portugal across several contexts. It is acknowledged that these professional roles vary and have their own characteristics, but the analysis of these is not the purpose of this current study. All of them engage with and contribute to the same broad scientific field, and by grouping them, a broader understanding of the geoscience community's collective experiences and perspectives on science communication can be obtained, an area that is still scarcely studied.

The sample is gender-balanced, with a significant portion over 41 years old (56%). The majority holds Ph.D. or Master's degree. Most respondents completed their undergraduate studies primarily in Geology (70%), with other areas including Natural Sciences Education, Geological and Mining Engineering, Geophysics, Oceanography, and Geography also represented.

The study collected 179 valid responses from across all regions of Portugal, encompassing diverse sociodemographic groups, professional categories, and fields of expertise (detailed demographics in Supplementary material B). The representativeness of the population studied cannot be guaranteed, and caution is advised in generalizing the results.

3.2 ▪ *Methodology*

3.2.1 ▪ *Descriptive analysis (RQ1)*

In the initial stage, we conducted a descriptive statistical analysis to summarize and characterize the dataset. This provided an overview of communication practices and key contextual variables, offering initial insights into the data distribution.

3.2.2 ▪ *Categorical principal component analysis (CatPCA, RQ2)*

To explore how communication goals (Q34) relate to targeted audiences (Q13), we applied CatPCA, a technique specifically designed for nominal or ordinal data [Agresti, 2013]. This approach simplifies the data structure while preserving variability, allowing us to identify underlying dimensions in the survey responses [Florensa et al., 2021; Martins & Nunes, 2020; Vasu et al., 2021]. After converting each survey item into a factor, we used the princals function (in the Gifi package) to extract principal components. We then examined loadings tables and biplots to interpret these dimensions.

3.2.3 ▪ *Association tests and clustering analysis (RQ3)*

To examine relationships among training (Q10), self-efficacy (Q30.1), and communication practices (Q11.), we used two main methods:

- Cramér's V, to measure the strength of association between pairs of categorical variables.
- Kruskal-Wallis, a non-parametric test for determining if self-efficacy levels vary across different groups (for example, trained vs. untrained, or low vs. high engagement).

The detailed numeric outputs for both tests are provided in Supplementary material C).

To identify distinct communication profiles, we applied Partitioning Around Medoids (PAM), well-suited for categorical data [Shokri et al., 2023]. We relied on the silhouette method to determine the optimal number of clusters, ensuring an interpretable grouping based on training status, self-efficacy, and communication practices.

The silhouette plot and its interpretation, including the average silhouette width and cluster cohesiveness, can be found in Supplementary material C.

3.2.4 ▪ *Software and packages*

All analyses were performed in R [version 4.3.2, R Core Team, 2024]. We employed packages such as FactoMineR [Husson et al., 2024], factoextra [Kassambara & Mundt, 2020], Gifi [Mair & De Leeuw, 2022], and vegan [Oksanen et al., 2025] to implement the methods described above.

4 ▪ Results

4.1 ▪ *Practices and audiences (RQ1)*

This study provides a number of insights into how members of the geoscience community might consciously think about and design their communication activities.

The analysis of descriptive statistics for key indicators, such as goals, target audiences, perceived audience attitudes, activity types, bidirectional experiences and communication tools, shows that members of the geoscience community surveyed are driven by perceptions of a public knowledge deficit (Figure 1 and Supplementary material B with detailed results).

These results indicate that generally, those in the geoscience community aim to provide more and better information to the public, enhancing their understanding, with more than 85% seeking to demonstrate the relevance of geoscience in everyday life. This may be explained by the field's low visibility in public discourse.

Regarding the audiences, the geoscience community primarily targets students, geoscience teachers, and researchers, all of whom have varying degrees of exposure to and knowledge of geoscience due to their roles and responsibilities. In contrast, journalists, non-governmental organizations, politicians, and local communities (audiences without geoscientific backgrounds) are less frequently targeted, despite often facing geoscientific issues that can affect them.

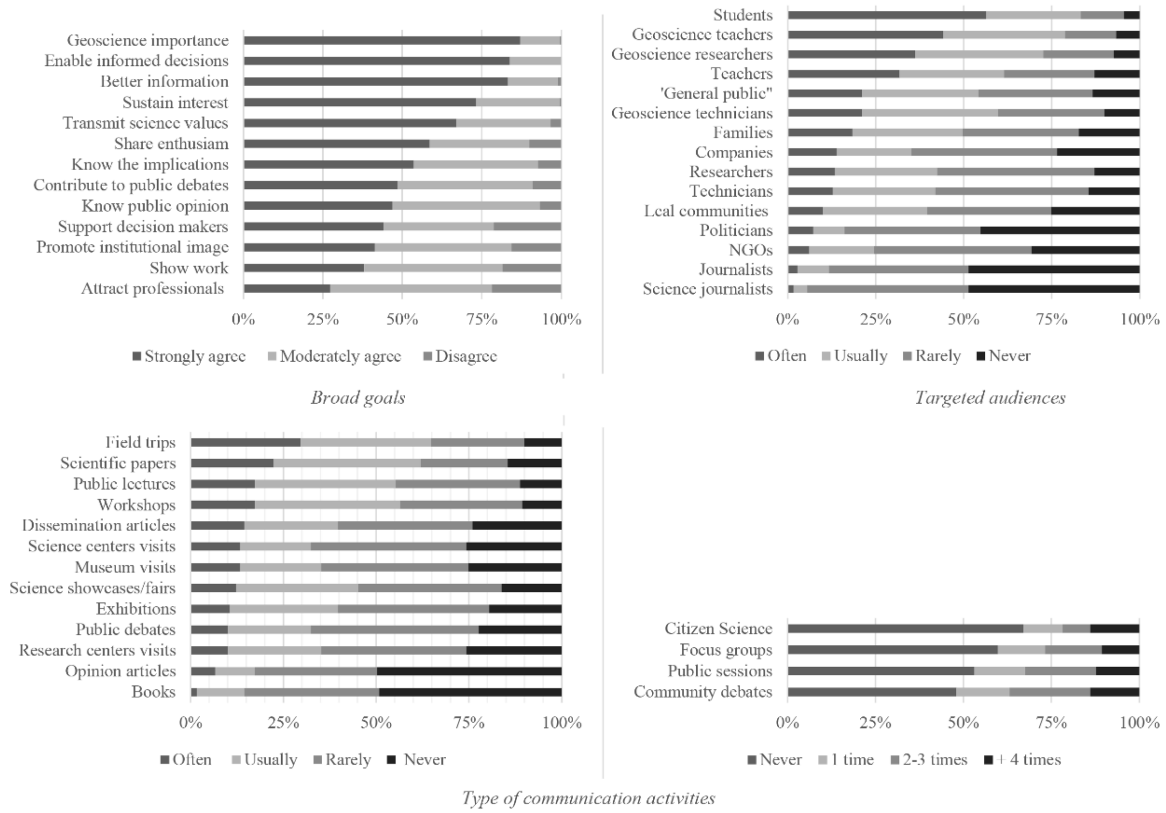

Figure 1. Descriptive analysis: broad goals for public engagement, frequency of public communication with different audiences, frequency and type of public engagement and frequency of participation specially in dialogical and participative two-way approaches.

Concerning the types of public engagement, field trips are most reported, reflecting the discipline's emphasis on firsthand observation and understanding in natural settings. This is followed by scientific papers, a format used among peers, and public lectures, typically attended by peers, students, or highly interested audiences. Interestingly, papers were noted by few participants as effective tools for communication. In contrast, the results show minimal engagement in dialogical approaches like citizen science projects, focus groups, or public debates, with nearly 50% never participating in these activities.

It is also important to highlight that many in the geoscience community perceive the public's lack of interest and knowledge as barriers to effective communication.

All these findings reinforce a one-directional paradigm focused on the knowledge deficit of audiences.

4.2 ▪ *Patterns based on communication goals and target audiences (RQ2)*

To investigate how communication goals align with targeted audiences, we applied Categorical Principal Component Analysis (CatPCA), a technique suited for nominal or ordinal survey data. This method reduces and simplifies the data structure while preserving essential variability, allowing us to identify key underlying components.

Table 1. Eigenvalues and proportion explained by the first two CatPCA components (the small-to-moderate percentage of explained variance is common in social science contexts with heterogeneous categorical data).

Component	*Eigenvalue*	*Proportion explained*
Comp1	6.8221	24.36%
Comp2	4.1751	14.91%
Cumulative	–	39.27%

Table 1 shows the eigenvalues and the proportion of variance explained by the first two principal components extracted through CatPCA. Together, these components account for 39.27% of the total variance in the “goals” and “audiences” variables.

These results reveal:

- Component 1 (24.36% explained variance): this axis captures primary relationships between communication goals and certain audiences. High positive loadings often come from public, local communities and families, aligning with goals such as ensuring the public is well-informed, sharing enthusiasm for geosciences and supporting community-focused decisions. Consequently, this dimension suggests a ‘community-oriented’ or ‘public impact advocate’ approach, emphasizing broad outreach, education and tangible societal relevance.
- Component 2 (14.91% explained variance, 39.27% cumulative): this axis provides additional insights into more specialized connections. Goals related to transmitting science values or understanding public opinion cluster with audiences like NGOs and decision makers. Such a pattern implies a ‘policy-driven’ or ‘science advocate’ communicator, highlighting evidence-based decisions, stakeholder engagement and deeper discussion of geoscientific content.

Together, these two components reveal two overarching patterns of engagement with various audiences: a community-oriented profile, prioritizing broad public engagement, local impacts and outreach, and policy-driven profile, focusing on influencing decision-making bodies, sustaining scientific rigor, and integrating public opinion into policy contexts.

Table 2 details the loadings of each variable (goal or audience) on Comp1 and Comp2, with a cutoff of 0.10.

Figure 2 provides a biplot of these results, situating each goal or audience variable in the two-dimensional space defined by Comp1 and Comp2. Points toward the right reflect higher loadings on Comp1 (broad public engagement), whereas those higher up reflect stronger loadings on Comp2 (informational/values-driven focus).

In summary, regarding CatPCA (RQ2), Component 1 aligns with a ‘community-oriented’ or “public impact” approach, while Component 2 aligns with a ‘policy-driven’ or ‘science advocate’ perspective. These two components collectively reveal how various communication goals and targeted audiences group together. Ultimately, this two-dimensional solution provides a nuanced understanding of whether practitioners focus on engaging the broader public and local communities or on addressing specialized audiences with more in-depth scientific information and policy guidance.

Table 2. Loadings of variables on the first two principal components (cutoff = 0.1). Eigenvalues: Comp1 = 6.8221 (24.36%), Comp2 = 4.1751 (14.91%), Cumulative = 39.27%. The “Type” column indicates whether each variable is a “goal” or “audience”. Loadings below ±0.10 are omitted.

Variable	*Comp1*	*Comp2*	*Type*
Implications	0.589	0.426	Goal
Journalists	0.538	−0.233	Audience
Science journalists	0.587	−0.231	Audience
Teachers	0.556	−0.401	Audience
Geoscience technicians	0.519	−0.320	Audience
Researchers	0.552	−0.304	Audience
Families	0.524	−0.349	Audience
Politicians	0.522	−0.385	Audience
NGOs	0.529	−0.421	Audience
Local communities	0.660	−0.366	Audience
Public	0.686	−0.266	Audience
Interest	0.373	0.549	Goal
Information	0.464	0.591	Goal
Science values	0.459	0.515	Goal
Public opinion	0.467	0.542	Goal
Importance	0.416	0.487	Goal
Enthusiasm	0.488	0.330	Goal
Informed decisions	0.474	0.440	Goal
Decision makers	0.373	0.344	Goal
Show work	0.360	0.338	Goal
Public debates	0.473	0.493	Goal
Professionals attraction	0.475	0.269	Goal
Institution image	0.368	0.289	Goal
Students	0.454	−0.199	Audience
Geoscience teachers	0.466	−0.372	Audience
Technician	0.499	−0.374	Audience
Companies	0.345	−0.367	Audience
Research geoscientists	0.399	−0.215	Audience

4.3 ▪ Associations between training, self-efficacy, and practice (RQ3)

To investigate the relationships among training, self-efficacy and communication practices, we employed two main methods:

- Cramér’s V to measure the strength of association between training (categorical) and each communication practice (categorical).
- Kruskal-Wallis to compare self-efficacy distributions (numeric) across different training (yes/no) and across practice frequency categories.

Table 3 presents the Cramér’s V values for Training versus each communication practice. Statistically significant associations ($p < 0.05$) are marked with an asterisk. We observe moderate associations with museums, science centres and science showcases/fairs, suggesting that individuals who receive training may be more inclined to engage in these public-oriented activities. In contrast, field trips, research institutions and most other practices show weaker or non-significant associations. Exhibitions is near significance ($p = 0.0646$).

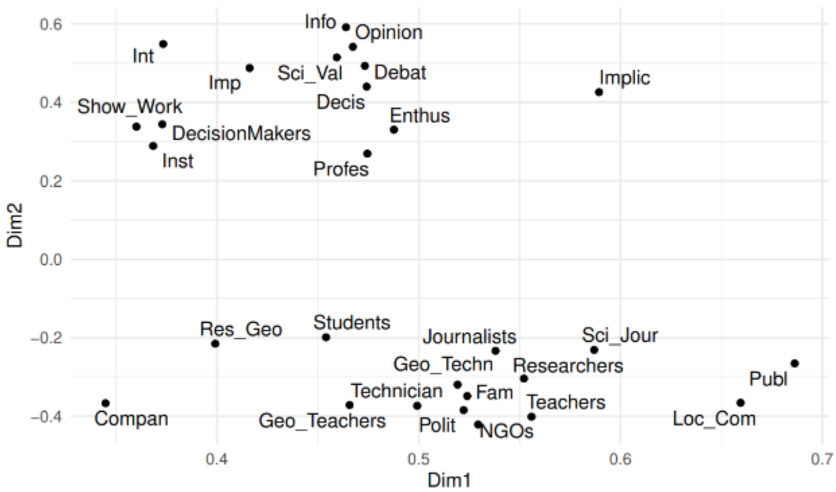

Figure 2. CatPCA Biplot. Variables with higher positive loadings on Component 1 appear toward the right, indicating emphasis on broad societal engagement. Variables with higher positive loadings on Component 2 appear at the top, highlighting a more informational/dialogical orientation. Negative loadings appear to the left (Comp1) or bottom (Comp2).

Table 3. Cramér's V: training vs. communication practices (* indicate $p < 0.05$; "ns" = not significant).

Practice	*Cramér's V*	*p-value*	*Significance*
Field trip	0.0895	0.4884	ns
Museums	0.2708	0.0014	* (moderate)
Science centres	0.2672	0.0017	* (moderate)
Research centres	0.1135	0.3158	ns
Workshops	0.1257	0.2434	ns
Exhibitions	0.1750	0.0646	ns (borderline)
Lectures	0.0544	0.7675	ns
Debates	0.1368	0.1872	ns
Science showcases/fairs	0.2143	0.0164	* (moderate)
Books	0.1174	0.2910	ns
Scientific papers	0.0599	0.7250	ns
Dissemination articles	0.1377	0.1831	ns
Opinion articles	0.0825	0.5441	ns

Next, Kruskal-Wallis tests were performed to see whether "self-efficacy" differs based on "training" (yes/no) and across the frequency levels of selected practices (e.g., field trips). Table 4 summarizes two key comparisons:

- training vs. self-efficacy: a significant difference (chi-squared = 6.5932; $p = 0.01024$) indicates that trained individuals report higher self-efficacy

- field trips vs. self-efficacy: varying frequencies of field trip participation also show significant differences (chi-squared = 10.839; p = 0.00443), suggesting hands-on engagement can positively influence confidence in communication.

Table 4. Kruskal-Wallis tests for self-efficacy.

Comparison	*Chi-squared*	*df*	*p-value*	*Interpretation*
Training vs. Self-efficacy	6.5932	1	0.01024	Significant difference (trained > untrained)
Field trip vs. Self-efficacy	10.839	2	0.00443	Significant across frequency levels

These findings highlight the importance of formal training and practical engagement. Training appears to encourage participation in certain public-facing practices (e.g., museums, science exhibitions) and correlates with higher self-efficacy. Additionally, active involvement in field trips is associated with greater confidence in communication. This underscores how both structured training and more hands-on experiences can enhance the geoscience community's perceived competence and willingness to engage with the public.

To further explore how training, self-efficacy and practices combine to shape communication profiles, we applied the PAM (Partitioning Around Medoids) algorithm on the relevant categorical variables (training, self-efficacy and activities). The silhouette method suggested an optimal solution of two clusters (see Supplementary material C for details).

Cluster characteristics (Table 5):

- Cluster 1 ('reserved'): consists mainly of members who rarely engage in most communication practices and tend to have moderate self-efficacy. The majority are also untrained, though a few trained individuals are present.
- Cluster 2 ('enthusiasts'): includes members who often participate in various communication activities, report higher self-efficacy and likewise mostly have no formal training.

Despite the low incidence of training in both clusters, these profiles underscore two different engagement patterns: a more reserved group vs. a more enthusiastic group. Because few participants reported having training at all, we did not observe a distinct 'trained cluster'.

Regarding the association of training and practices, training correlates significantly with certain public-oriented activities (museums, science centres, and science showcases/fairs) and higher self-efficacy, but not with field trips or other practices.

Clustering outcomes show two primary profiles. Most members of the geoscience community, including the 'reserved' cluster, do not hold formal training certificates, which may limit broader engagement. Meanwhile, 'enthusiasts' communicate frequently and demonstrate higher self-efficacy, although they, too, rarely possess formal training. These results suggest that fostering formal communication training and encouraging active participation (e.g., field trips, showcases) could increase overall competence and confidence across the community.

In conclusion, PAM indicates two distinct but predominantly untrained clusters of communicators. Strengthening formal training initiatives may help unify best practices and improve overall communication effectiveness in the geosciences.

Table 5. Full cluster centers for the two identified clusters. Note that “2 (no)” under training indicates that none of the individuals in either cluster had formal communication training as a majority attribute, reflecting the low presence of training in the sample. “2 (rarely)” vs. “3 (often)” under specific activities (e.g., museums, science fairs denotes the dominant response category for each cluster. A higher number (3) corresponds to “frequent” or “often”, whereas 2 corresponds to “rarely”. Self-Efficacy being “2 (moderately)” in Cluster 1 and “3 (well)” in Cluster 2 highlights the difference in perceived confidence levels between the two groups.

Variable	*Cluster 1 (“Reserved”)*	*Cluster 2 (“Enthusiasts”)*
Training	2 (No)	2 (No)
Self-efficacy	2 (Moderately)	3 (Well)
Field trip	2 (Rarely)	3 (Often)
Museums	2 (Rarely)	3 (Often)
Science centres	2 (Rarely)	3 (Often)
Research centres	2 (Rarely)	3 (Often)
Workshop	2 (Rarely)	3 (Often)
Exhibition	2 (Rarely)	3 (Often)
Lectures	2 (Rarely)	3 (Often)
Debates	2 (Rarely)	3 (Often)
Science fairs/showcases	2 (Rarely)	3 (Often)
Books	2 (Rarely)	2 (Rarely)
Scientific papers	2 (Rarely)	3 (Often)
Dissemination articles	2 (Rarely)	3 (Often)
Opinion articles	2 (Rarely)	2 (Rarely)

Additionally, we performed Chi-square tests to investigate the relationship between training and the frequency of communication with specific audiences and participation in certain activities. The results showed statistically significant associations for the following:

Families: $\chi^2 = 6.7535$, $p = 0.03416$
Museums: $\chi^2 = 13.1310$, $p = 0.001408$
Science centers: $\chi^2 = 12.7830$, $p = 0.001676$
Science showcases/fairs: $\chi^2 = 8.2204$, $p = 0.0164$

Meanwhile, communication with local communities ($\chi^2 = 5.1719$, $p = 0.07532$) did not reach the conventional 5% significance threshold, although it suggests a possible trend. Overall, these findings indicate that those in the geoscience community with training are more likely to engage with particular audiences (e.g., families) and in certain activities (visits to museums, science centers, science fairs), underscoring the positive impact of formal communication training.

The following Table 6 compiles the main patterns identified regarding (1) communication goals and target audiences, as well as (2) training, self-efficacy, and practices.

By integrating these two perspectives, the study highlights the importance of training in shaping how the geoscience community communicates (i.e., with which audiences and via which activities), as well as their overall self-efficacy and likelihood to engage. The significant associations found for certain publics and events suggest that targeted training could help broaden or deepen engagement.

Table 6. Summary of patterns and profiles identified through CatPCA and PAM: CatPCA identified two overarching dimensions, distinguishing "community-oriented" vs. "policy-driven" communication and PAM clustering revealed two distinct communicator profiles — "reserved" and "enthusiasts" — based on their training, self-efficacy and communication practices.

Category	*Details*
Associations based on communication goals and target audiences (CatPCA)	
Main dimensions	Dimension 1: "Community-oriented" / "Public impact advocate" Dimension 2: "Policy-driven" / "Science advocate"
Audiences	Public, local communities, NGOs, decision makers (also families, politicians, science journalists)
Goals	Inform, share enthusiasm, support decision-makers, transmit science values, understand public opinion, contribute to public debates, etc.
Clusters based on training, self-efficacy, and practices (PAM)	
Profiles	'Reserved' (Cl1): Rare engagement, moderate self-efficacy 'Enthusiasts' (Cl2): Frequent engagement, high self-efficacy
Training	Training mostly absent in both clusters due to low prevalence
Self-efficacy	Moderate in Cl1 High in Cl2
Engagement in activities	Cl1: Rare participation Cl2: Frequent participation

5 ▪ Discussion and conclusion

Given the scarcity of studies investigating the science communication practices of members of the geoscience community, this research provides an analysis of communication perceptions and approaches, along with empirical evidence of systematic group differences.

The study finds that while the Portuguese community values public engagement and effective strategies, these insights are not consistently applied. A significant conclusion requiring further exploration is the influence of limited formal communication training, alongside broader institutional and cultural factors, on science communication practices. This research highlights a gap between the geoscience community's perceptions and practices, as well as between science communication theory and practice. In the absence of structured training, practitioners tend to default to traditional, experience-driven approaches, often due to limited awareness of the advantages and potential of more dialogical and participatory approaches. However, it is important to recognize that training alone is not sufficient. Without organizational support and structures that actively value participatory approaches, even well-trained individuals may find it difficult to implement them in practice [Langkjær & Hyldgård, 2021]. Additionally, different science communication models can, and often do, coexist within real-world contexts, further complicating the relationship between theory and practice [Metcalfe, 2022].

In response to RQ1, we performed descriptive analysis of key indicators, such as goals, target audiences, perceived audience attitudes and practices. These showed that many communication approaches persisted in aligning with the deficit model, relying on personal previous experience to target audiences perceived as having limited knowledge, favoring unidirectional methods typical of formal education. Although the exact way in which members of the geoscience community are consciously considering and planning their communication efforts and activities is unclear, these indicators implicitly support this conclusion.

This strong emphasis on information transfer, rooted in the belief that objections and controversies arise from poor communication [Gibson & Roberts, 2018; Ickert & Stewart, 2016; Stewart & Nield, 2013], in a field where the economic, social and political impacts of the issues, are enormous and deserve further reflection.

This and other studies also show that scientists recognize the importance of bidirectional approaches and real engagement [Calice et al., 2023; Davies, 2021; Scheufele et al., 2021], although they often struggle to apply this in practice. Scientists seem uncomfortable with dialogic and participatory approaches, viewing communication with non-specialists comparable to instructing students, as merely simplifying, translating, and delivering content. This education-centered outreach may be explained by the fact that they most frequently interact with teachers and students [Besley et al., 2015; Dudo & Besley, 2016; Entradas & Bauer, 2017; Royal Society, 2006]. These unidirectional approaches also show limited understanding of the public's relationships with science and of their expectations [Besley, 2015]. The resistance to paradigm shifts may be explained by limited research influence and lack of formal training [Seethaler et al., 2019; Simis et al., 2016], as discussed. It is important to underline that one-way dissemination approaches can be relevant in the early stages of dialogue and co-creation processes, involving the discussion of accurate, up-to-date and accessible information [Illingworth, 2023; Stewart, 2024]. However, this progression often does not reflect the real context.

Concerning RS2, we used Categorical Principal Component Analysis (CatPCA) to uncover patterns among communication goals and audiences. Rather than relying on linear assumptions, CatPCA is specifically suited to nominal/ordinal data, simplifying multiple survey items while retaining their variability. From this analysis, we identified four distinct patterns (or "profiles") describing how members of the geoscience community combine goals (e.g., informing, sharing enthusiasm, supporting decision-makers) with various audiences (e.g., local communities, NGOs, decision makers). For simplicity, these patterns can be seen as two major axes (community-oriented vs. more specialized/policy-driven engagement) and sub-variations emphasizing public impact or science advocacy.

Notably, no purely "educational-only" profile emerged, as many within the geoscience community blend educational purposes within wider efforts. Nor did we find an unequivocal separation of "community-oriented" versus "policy-driven" extremes; instead, these reflect underlying dimensions rather than strict categories. Additionally, the patterns identified do not provide a definitive position towards the existing communication paradigms.

These conclusions reflect the complex nature of science communication among members of the geoscience community, as well as the challenges they face in positioning their goals and practices. However, as several authors have pointed out, a mix of science communication models often coexists in practice [Metcalfe, 2019; Stewart, 2024]. This plurality may reflect not only inconsistencies or gaps in training, but also deliberate, context-sensitive choices by practitioners who draw on different models to suit specific audiences, goals or institutional settings.

Regarding RQ3, tests revealed meaningful relationships between training, self-efficacy and communication practices. Although formal communication training is rare, our results indicate it has a significant impact on self-efficacy. Further, performing field trip activities correlates with higher self-efficacy, probably because field trips are the most defining activities in geoscience, offering real-world settings that demand holistic approaches and specific skills to communicate multi-dimensional processes. We also observe a strong link between certain related communication activities (e.g., visits to museums and science centers), in that members of the geoscience community who frequently do one often do the other as well. However, scientists' self-efficacy may not always mirror actual quality or effectiveness of engagement, though it influences how activities are designed and implemented, which we know to be predominantly linear.

Finally, to identify distinct "communication profiles", we applied the PAM algorithm on variables including training (yes/no), self-efficacy (low/moderate/high) and practices (rarely/often). The silhouette method indicated an optimal solution of two clusters, both surprisingly lacking a predominantly 'trained' contingent (likely due to the low incidence of training in our dataset).

1. Cluster 1 ('reserved'):
   - members who rarely engage in communication activities;
   - generally have moderate self-efficacy;
   - mostly untrained in formal communication.
2. Cluster 2 ('enthusiasts'):
   - members who frequently participate in numerous communication activities (e.g., science showcases/fairs, museums);
   - tend to have higher self-efficacy;
   - also largely untrained, reflecting the overall sample.

Since few individuals reported training, no separate 'trained' cluster emerged. This likely reflects the typical structure of university courses in geosciences, where specific training in communication is generally not included.

These two profiles underscore how members of the geoscience community differ in their frequency of engagement and self-efficacy but remain consistent in the limited availability of formal communication training.

Overall, integrating the findings, this study reveals six discernible groupings: four main patterns from CatPCA (community/policy axes plus sub-variations) and two further clusters (Reserved vs. Enthusiasts) from PAM. Although these methods differ in nature — CatPCA for identifying variable-level patterns and PAM for clustering individuals — their outcomes complement each other. On one hand, statistical association methods (Cramér's V, Kruskal-Wallis, CatPCA) shed light on relationships among variables; on the other hand, clustering (PAM) highlights how these variables combine within specific profiles.

This research, focusing on the geoscience community in Portugal, offers valuable insights, methodologies, and analytical approaches for improving science communication — both within geoscience and other fields. The detected profiles (four via CatPCA, two via PAM) confirm that communication goals and target audiences differ systematically and underscore the positive role of training and practical, hands-on activities (like field trips) in building self-efficacy.

Nonetheless, the limited availability of training opportunities may contribute to the challenges scientists face in adopting more dialogical, participatory models of communication, an issue echoed in the literature [Dudo et al., 2021; Besley & Tanner, 2011]. Expanding international scope and adding qualitative methods (e.g., interviews) could refine these findings further, but our sample's diversity aligns with prior studies enough to support confidence in the results.

Limitations include potential self-selection bias (more communicative subjects may be overrepresented), and the low prevalence of mentions of training limits the analysis of trained subgroups. Meanwhile, CatPCA itself can lose nuance when encoding categorical data, and clustering solutions (like PAM) reflect the data's structure and coding choices. Regarding the analyses (CatPCA and PAM), these should be considered exploratory, highlighting the low variance explained (39%), which is common in social sciences but warrants caution. It is equally important to underscore that clustering is used to identify potential profiles, not to draw definitive conclusions. Despite these constraints, the combined approach revealed nuanced insights that single-method approaches might have missed, strengthening the empirical basis for discussing systematic differences and designing targeted communication interventions.

Ultimately, these findings reinforce the call for enhanced dialogue-based approaches and tailored training programs to help the geoscience community communicate more effectively. The profiles identified may guide policymakers and institutions in offering more customized support, whether bridging knowledge gaps, fostering public engagement, or shaping evidence-based decisions in geoscience-related domains.

Considering the understanding within the field, the outcomes were not unexpected, and the results confirmed profiles that had been previously foreseen but are now being empirically demonstrated for the first time.

The current results, together with the previous studies [Rodrigues, Castro et al., 2023], provide a comprehensive view of the perceptions and experiences of the geoscience community, predicting factors that influence public engagement and identifying distinct profiles. These findings align with earlier discussions in geoscience communication [Rodrigues, Costa e Silva & Pereira, 2023], underscoring the need for dialogue-based approaches and enhanced collaboration between researchers and practitioners, through training incentives and other interventions.

Considering this study examines the geoscience community as a whole, future research could segment it by professional roles to better understand how these roles influence perceptions and practices.

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References

Agresti, A. (2013). *Categorical data analysis* (3rd ed.). Wiley-Interscience.

Altman, K., Yelton, B., Hart, Z., Carson, M., Schandera, L., Kelsey, R. H., Porter, D. E., & Friedman, D. B. (2020). "You gotta choose your words carefully": findings from interviews with environmental health scientists about their research translation perceptions and training needs. *Journal of Health Communication*, *25*(5), 454–462. https://doi.org/10.1080/10810730.2020.1785060

Anjos, S., Russo, P., & Carvalho, A. (2021). Communicating astronomy with the public: perspectives of an international community of practice. *JCOM*, *20*(03), A11. https://doi.org/10.22323/2.20030211

Anzolini, C. (2022). *Outreach and public engagement of Italian Departments of Earth Sciences* [Master's Thesis]. SISSA — International School for Advanced Studies. https://hdl.handle.net/20.500.11767/126809

Bankston, A., & McDowell, G. S. (2018). Changing the culture of science communication training for junior scientists. *Journal of Microbiology & Biology Education*, *19*(1). https://doi.org/10.1128/jmbe.v19i1.1413

Baram-Tsabari, A., & Lewenstein, B. V. (2017). Science communication training: what are we trying to teach? *International Journal of Science Education, Part B*, *7*(3), 285–300. https://doi.org/10.1080/21548455.2017.1303756

Bauer, M. W. (2009). The evolution of public understanding of science — discourse and comparative evidence. *Science, Technology and Society*, *14*(2), 221–240. https://doi.org/10.1177/097172180901400202

Bauer, M. W., Allum, N., & Miller, S. (2007). What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Understanding of Science*, *16*(1), 79–95. https://doi.org/10.1177/0963662506071287

Besley, J. C. (2015). What do scientists think about the public and does it matter to their online engagement? *Science and Public Policy*, *42*(2), 201–214. https://doi.org/10.1093/scipol/scu042

Besley, J. C., & Dudo, A. (2022). *Strategic science communication: a guide to setting the right objectives for more effective public engagement*. Johns Hopkins University Press. https://doi.org/10.56021/9781421444215

Besley, J. C., Dudo, A., & Storksdieck, M. (2015). Scientists' views about communication training. *Journal of Research in Science Teaching*, *52*(2), 199–220. https://doi.org/10.1002/tea.21186

Besley, J. C., & Nisbet, M. (2013). How scientists view the public, the media and the political process. *Public Understanding of Science*, *22*(6), 644–659. https://doi.org/10.1177/0963662511418743

Besley, J. C., Oh, S. H., & Nisbet, M. (2013). Predicting scientists' participation in public life. *Public Understanding of Science*, *22*(8), 971–987. https://doi.org/10.1177/0963662512459315

Besley, J. C., O'Hara, K., & Dudo, A. (2019). Strategic science communication as planned behavior: understanding scientists' willingness to choose specific tactics. *PLoS ONE*, *14*(10), e0224039. https://doi.org/10.1371/journal.pone.0224039

Besley, J. C., & Tanner, A. H. (2011). What science communication scholars think about training scientists to communicate. *Science Communication*, *33*(2), 239–263. https://doi.org/10.1177/1075547010386972

Bray, B., France, B., & Gilbert, J. K. (2012). Identifying the essential elements of effective science communication: what do the experts say? *International Journal of Science Education, Part B*, *2*(1), 23–41. https://doi.org/10.1080/21548455.2011.611627

Brilha, J. (2004). A geologia, os geólogos e o manto da invisibilidade. *Comunicação e Sociedade*, *6*, 257–265. https://doi.org/10.17231/comsoc.6(2004).1238

Bubela, T., Nisbet, M. C., Borchelt, R., Brunger, F., Critchley, C., Einsiedel, E., Geller, G., Gupta, A., Hampel, J., Hyde-Lay, R., Jandciu, E. W., Jones, S. A., Kolopack, P., Lane, S., Lougheed, T., Nerlich, B., Ogbogu, U., O'Riordan, K., Ouellette, C., … Caulfield, T. (2009). Science communication reconsidered. *Nature Biotechnology*, *27*(6), 514–518. https://doi.org/10.1038/nbt0609-514

Bucchi, M., & Trench, B. (2021). Rethinking science communication as the social conversation around science. *JCOM*, *20*(03), Y01. https://doi.org/10.22323/2.20030401

Calice, M. N., Bao, L., Beets, B., Brossard, D., Scheufele, D. A., Feinstein, N. W., Heisler, L., Tangen, T., & Handelsman, J. (2023). A triangulated approach for understanding scientists' perceptions of public engagement with science. *Public Understanding of Science*, *32*(3), 389–406. https://doi.org/10.1177/09636625221122285

Copple, J., Bennett, N., Dudo, A., Moon, W.-K., Newman, T. P., Besley, J., Leavey, N., Lindenfeld, L., & Volpe, C. (2020). Contribution of training to scientists' public engagement intentions: a test of indirect relationships using parallel multiple mediation. *Science Communication*, *42*(4), 508–537. https://doi.org/10.1177/1075547020943594

Corley, E. A., Kim, Y., & Scheufele, D. A. (2011). Leading US nano-scientists' perceptions about media coverage and the public communication of scientific research findings. *Journal of Nanoparticle Research*, *13*(12), 7041–7055. https://doi.org/10.1007/s11051-011-0617-3

Costa e Silva, E., & Pinto, S. (2023). Disciplinary cultures and participation in international research networks: how science communication practices and motivation relate to contextual factors. *International Journal of Science Education, Part B*, *13*(3), 245–260. https://doi.org/10.1080/21548455.2022.2162831

Costa e Silva, E., Pinto, S., & Magalhães, O. E. (2024). Exploring the influence of disciplinary cultures and self-efficacy on the training needs of scientists in Portugal. *Cultures of Science*, *7*(3), 184–197. https://doi.org/10.1177/20966083241278008

Davies, S. R. (2021). An empirical and conceptual note on science communication's role in society. *Science Communication*, *43*(1), 116–133. https://doi.org/10.1177/1075547020971642

de Vries, S., Jansen, E. P. W. A., & van de Grift, W. J. C. M. (2013). Profiling teachers' continuing professional development and the relation with their beliefs about learning and teaching. *Teaching and Teacher Education*, *33*, 78–89. https://doi.org/10.1016/j.tate.2013.02.006

Dohaney, J., Brogt, E., Kennedy, B., Wilson, T. M., & Lindsay, J. M. (2015). Training in crisis communication and volcanic eruption forecasting: design and evaluation of an authentic role-play simulation. *Journal of Applied Volcanology*, *4*, 12. https://doi.org/10.1186/s13617-015-0030-1

Dudo, A., & Besley, J. C. (2016). Scientists' prioritization of communication objectives for public engagement. *PLoS ONE*, *11*(2), e0148867. https://doi.org/10.1371/journal.pone.0148867

Dudo, A., Besley, J. C., & Yuan, S. (2021). Science communication training in North America: preparing whom to do what with what effect? *Science Communication*, *43*(1), 33–63. https://doi.org/10.1177/1075547020960138

Dunwoody, S., Brossard, D., & Dudo, A. (2009). Socialization or rewards? Predicting U.S. scientist-media interactions. *Journalism & Mass Communication Quarterly*, *86*(2), 299–314. https://doi.org/10.1177/107769900908600203

Entradas, M., & Bauer, M. M. (2017). Mobilisation for public engagement: benchmarking the practices of research institutes. *Public Understanding of Science*, *26*(7), 771–788. https://doi.org/10.1177/0963662516633834

Entradas, M., Marcelino, J., Bauer, M. W., & Lewenstein, B. (2019). Public communication by climate scientists: what, with whom and why? *Climatic Change*, *154*, 69–85. https://doi.org/10.1007/s10584-019-02414-9

Florensa, D., Godoy, P., Mateo, J., Solsona, F., Pedrol, T., Mesas, M., & Piñol, R. (2021). The use of multiple correspondence analysis to explore associations between categories of qualitative variables and cancer incidence. *IEEE Journal of Biomedical and Health Informatics*, *25*(9), 3659–3667. https://doi.org/10.1109/JBHI.2021.3073605

Gaikwad, D., & Lamkuche, H. (2021). Segmentation of services provided by e-commerce platforms using PAM clustering. *Journal of Physics: Conference Series*, *1964*(4), 042036. https://doi.org/10.1088/1742-6596/1964/4/042036

Gascoigne, T., Schiele, B., Leach, J., Riedlinger, M., Lewenstein, B. V., Massarani, L., & Broks, P. (Eds.). (2020). *Communicating science: a global perspective*. ANU Press. https://doi.org/10.22459/CS.2020

Gerber, A., Broks, P., Gabriel, M., Lorenz, L., Lorke, J., Merten, W., Metcalfe, J., Müller, B., & Warthun, N. (2020). *Science communication research: an empirical field analysis*. Edition Innovare. https://doi.org/10.5281/zenodo.4028704

Gibson, H., & Roberts, J. (2018). Communicating geoscience in uncertain times. *Geoscientist*, *28*(11), 26–27. https://doi.org/10.1144/geosci2018-031

Greer, S., Alexander, H., Baldwin, T. O., Freeze, H. H., Thompson, M., Hunt, G., & Snowflack, D. R. (2018). The art of science communication — a novel approach to science communication training. *Journal of Microbiology & Biology Education*, *19*(1). https://doi.org/10.1128/jmbe.v19i1.1547

Han, H., & Stenhouse, N. (2015). Bridging the research-practice gap in climate communication: lessons from one academic-practitioner collaboration. *Science Communication*, *37*(3), 396–404. https://doi.org/10.1177/1075547014560828

Henriques, L., Castro, C., Prata, F., Leiva, V., & Venegas, R. (2024). Modeling residential energy consumption patterns with machine learning methods based on a case study in Brazil. *Mathematics*, *12*(13), 1961. https://doi.org/10.3390/math12131961

Husson, F., Josse, J., Le, S., & Mazet, J. (2024). FactoMineR: multivariate exploratory data analysis and data mining [R package version 2.4]. https://doi.org/10.32614/CRAN.package.FactoMineR

Ickert, J., & Stewart, I. S. (2016). Earthquake risk communication as dialogue — insights from a workshop in Istanbul's urban renewal neighbourhoods. *Natural Hazards and Earth System Sciences*, *16*(5), 1157–1173. https://doi.org/10.5194/nhess-16-1157-2016

Illingworth, S. (2023). A spectrum of geoscience communication: from dissemination to participation. *Geoscience Communication*, *6*(4), 131–139. https://doi.org/10.5194/gc-6-131-2023

Jensen, E. A., & Gerber, A. (2020). Evidence-based science communication. *Frontiers in Communication*, *4*, 78. https://doi.org/10.3389/fcomm.2019.00078

Jensen, P. (2011). A statistical picture of popularization activities and their evolutions in France. *Public Understanding of Science*, *20*(1), 26–36. https://doi.org/10.1177/0963662510383632

Kahan, D. M. (2013). Making climate-science communication evidence-based — all the way down. In D. A. Crow & M. T. Boykoff (Eds.), *Culture, politics and climate change: how information shapes our common future* (pp. 203–220). Routledge. https://doi.org/10.2139/ssrn.2216469

Kassambara, A., & Mundt, F. (2020). factoextra: extract and visualize the results of multivariate data analyses [R package version 1.0.7]. https://doi.org/10.32614/CRAN.package.factoextra

Ke, Q., Ahn, Y.-Y., & Sugimoto, C. R. (2017). A systematic identification and analysis of scientists on Twitter. *PLoS ONE*, *12*(4), e0175368. https://doi.org/10.1371/journal.pone.0175368

Langkjær, F., & Hyldgård, P. (2021). *Opportunities and barriers for strengthening the quality of interaction between science and society. RETHINK project report*. https://www.rethinkscicomm.eu/wp-content/uploads/2021/06/RETHINK_D5.1_Working-Paper-Taking-stock-of-science-communication-1.pdf

Light, N., Fernbach, P. M., Rabb, N., Geana, M. V., & Sloman, S. A. (2022). Knowledge overconfidence is associated with anti-consensus views on controversial scientific issues. *Science Advances*, *8*(29), eabo0038. https://doi.org/10.1126/sciadv.abo0038

Liverman, D. (2009). Communicating geological hazards: educating, training and assisting geoscientists in communication skills. In T. Beer (Ed.), *Geophysical hazards: minimizing risk, maximizing awareness* (pp. 41–55). Springer. https://doi.org/10.1007/978-90-481-3236-2_4

Liverman, D., & Jaramillo, M. (2011). Communicating environmental geoscience — an international survey. *Episodes*, *34*(1), 25–31. https://doi.org/10.18814/epiiugs/2011/v34i1/004

Longnecker, N., & Gondwe, M. (2014). Graduate degree programmes in science communication: educating and training science communicators to work with communities. In L. Tan Wee Hin & R. Subramaniam (Eds.), *Communicating science to the public: opportunities and challenges for the Asia-Pacific region* (pp. 141–160). Springer. https://doi.org/10.1007/978-94-017-9097-0_9

Mair, P., & De Leeuw, J. (2022). Gifi: multivariate analysis with optimal scaling [R package version 1.0-1]. https://doi.org/10.32614/CRAN.package.Gifi

Martins, B., & Nunes, A. (2020). Exploring flash flood risk perception using PCA analysis: the case of Mindelo, S. Vicente (Cape Verde). *The Geographical Journal*, *186*(4), 375–389. https://doi.org/10.1111/geoj.12357

Mejlgaard, N., & Ryan, T. K. (2017). Patterns of third mission engagement among scientists and engineers. *Research Evaluation*, *26*(4), 326–336. https://doi.org/10.1093/reseval/rvx032

Metcalfe, J. (2019). Comparing science communication theory with practice: an assessment and critique using Australian data. *Public Understanding of Science*, *28*(4), 382–400. https://doi.org/10.1177/0963662518821022

Metcalfe, J. (2022). Science communication: a messy conundrum of practice, research and theory. *JCOM*, *21*(07), C07. https://doi.org/10.22323/2.21070307

Miller, S. (2008). So where's the theory? On the relationship between science communication practice and research. In D. Cheng, M. Claessens, T. Gascoigne, J. Metcalfe, B. Schiele & S. Shi (Eds.), *Communicating science in social contexts: new models, new practices* (pp. 275–287). Springer. https://doi.org/10.1007/978-1-4020-8598-7_16

Miller, S., Fahy, D., & The ESConet Team. (2009). Can science communication workshops train scientists for reflexive public engagement? The ESConet experience. *Science Communication*, *31*(1), 116–126. https://doi.org/10.1177/1075547009339048

Mulder, H. A. J., Longnecker, N., & Davis, L. S. (2008). The state of science communication programs at universities around the world. *Science Communication*, *30*(2), 277–287. https://doi.org/10.1177/1075547008324878

Newman, T. P. (Ed.). (2019). *Theory and best practices in science communication training*. Routledge. https://doi.org/10.4324/9781351069366

Oksanen, J., Simpson, G. L., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O'Hara, R. B., Solymos, P., Stevens, M. H. H., Szoecs, E., Wagner, H., Barbour, M., Bedward, M., Bolker, B., Borcard, D., Borman, T., Carvalho, G., Chirico, M., De Caceres, M., … Weedon, J. (2025). vegan: community ecology package [R package version 2.5-7]. https://doi.org/10.32614/CRAN.package.vegan

Parrella, J. A., Koswatta, T. J., Leggette, H. R., Ramasubramanian, S., & Rutherford, T. (2022). Teaching scientists to communicate: developing science communication training based on scientists' knowledge and self-reflectiveness. *International Journal of Science Education, Part B*, *12*(3), 235–253. https://doi.org/10.1080/21548455.2022.2068809

Pedder, D. (2007). Profiling teachers' professional learning practices and values: differences between and within schools. *The Curriculum Journal*, *18*(3), 231–252. https://doi.org/10.1080/09585170701589801

Poliakoff, E., & Webb, T. L. (2007). What factors predict scientists' intentions to participate in public engagement of science activities? *Science Communication*, *29*(2), 242–263. https://doi.org/10.1177/1075547007308009

Priest, S. H. (2010). Coming of age in the academy? The status of our emerging field. *JCOM*, *09*(03), C06. https://doi.org/10.22323/2.09030306

R Core Team. (2024). R: a language and environment for statistical computing [Version 4.3.2]. https://www.R-project.org/

Rabb, N., Fernbach, P. M., & Sloman, S. A. (2019). Individual representation in a community of knowledge. *Trends in Cognitive Sciences*, *23*(10), 891–902. https://doi.org/10.1016/j.tics.2019.07.011

Ridgway, A., Milani, E., Weitkamp, E., & Wilkinson, C. (2020). *Report on the working practices, motivations and challenges of those engaged in science communication*. European Commission. https://uwe-repository.worktribe.com/output/6017685

Riedlinger, M., Massarani, L., Joubert, M., Baram-Tsabari, A., Entradas, M., & Metcalfe, J. (2019). Telling stories in science communication: case studies of scholar-practitioner collaboration. *JCOM*, *18*(05), N01. https://doi.org/10.22323/2.18050801

Rodgers, S., Wang, Z., & Schultz, J. C. (2020). A scale to measure science communication training effectiveness. *Science Communication*, *42*(1), 90–111. https://doi.org/10.1177/1075547020903057

Rodrigues, J., Castro, C., Costa e Silva, E., & Pereira, D. I. (2023). Geoscientists' views about science communication: predicting willingness to communicate geoscience. *Geoscience Communication*, *6*(1), 15–25. https://doi.org/10.5194/gc-6-15-2023

Rodrigues, J., Costa e Silva, E., & Pereira, D. I. (2023). How can geoscience communication foster public engagement with geoconservation? *Geoheritage*, *15*, 32. https://doi.org/10.1007/s12371-023-00800-5

Rose, K. M., Markowitz, E. M., & Brossard, D. (2020). Scientists' incentives and attitudes toward public communication. *Proceedings of the National Academy of Sciences*, *117*(3), 1274–1276. https://doi.org/10.1073/pnas.1916740117

Royal Society. (2006). *Factors affecting science communication*. The Royal Society, Research Councils UK, The Wellcome Trust. https://royalsociety.org/-/media/policy/publications/2006/2012-07-24-science-communication-dataanalysis.pdf

Salmon, R. A., & Roop, H. A. (2019). Bridging the gap between science communication practice and theory: reflecting on a decade of practitioner experience using polar outreach case studies to develop a new framework for public engagement design. *Polar Record*, *55*(4), 297–310. https://doi.org/10.1017/s0032247418000608

Scheufele, D. A., Krause, N. M., Freiling, I., & Brossard, D. (2021). What we know about effective public engagement on CRISPR and beyond. *Proceedings of the National Academy of Sciences*, *118*(22), e2004835117. https://doi.org/10.1073/pnas.2004835117

Seethaler, S., Evans, J. H., Gere, C., & Rajagopalan, R. M. (2019). Science, values, and science communication: competencies for pushing beyond the deficit model. *Science Communication*, *41*(3), 378–388. https://doi.org/10.1177/1075547019847484

Shokri, E., Razeghi, M., Shahraki, H. R., Jalli, R., & Motealleh, A. (2023). The use of cluster analysis by partitioning around medoids (PAM) to examine the heterogeneity of patients with low back pain within subgroups of the treatment based classification system. *Journal of Biomedical Physics and Engineering*, *13*(1), 89–98. https://doi.org/10.31661/jbpe.v0i0.2001-1047

Silva, J., & Bultitude, K. (2009). Best practice in communications training for public engagement with science, technology, engineering and mathematics. *JCOM*, *08*(02), A03. https://doi.org/10.22323/2.08020203

Simis, M. J., Madden, H., Cacciatore, M. A., & Yeo, S. K. (2016). The lure of rationality: why does the deficit model persist in science communication? *Public Understanding of Science*, *25*(4), 400–414. https://doi.org/10.1177/0963662516629749

Stewart, I. S. (2024). Advancing disaster risk communications. *Earth-Science Reviews*, *249*, 104677. https://doi.org/10.1016/j.earscirev.2024.104677

Stewart, I. S., & Nield, T. (2013). Earth stories: context and narrative in the communication of popular geoscience. *Proceedings of the Geologists' Association*, *124*(4), 699–712. https://doi.org/10.1016/j.pgeola.2012.08.008

Trench, B. (2008). Towards an analytical framework of science communication models. In D. Cheng, M. Claessens, T. Gascoigne, J. Metcalfe, B. Schiele & S. Shi (Eds.), *Communicating science in social contexts: new models, new practices* (pp. 119–135). Springer. https://doi.org/10.1007/978-1-4020-8598-7_7

Trench, B., & Miller, S. (2012). Policies and practices in supporting scientists' public communication through training. *Science and Public Policy*, *39*(6), 722–731. https://doi.org/10.1093/scipol/scs090

Uwizeyemungu, S., Bertrand, J., & Poba-Nzaou, P. (2020). Patterns underlying required competencies for CPA professionals: a content and cluster analysis of job ads. *Accounting Education*, *29*(2), 109–136. https://doi.org/10.1080/09639284.2020.1737157

Vasu, D., Tiwari, G., Sahoo, S., Dash, B., Jangir, A., Sharma, R. P., Naitam, R., Tiwary, P., Karthikeyan, K., & Chandran, P. (2021). A minimum data set of soil morphological properties for quantifying soil quality in coastal agroecosystems. *CATENA*, *198*, 105042. https://doi.org/10.1016/j.catena.2020.105042

Vermunt, J. D., & Endedijk, M. D. (2011). Patterns in teacher learning in different phases of the professional career. *Learning and Individual Differences*, *21*(3), 294–302. https://doi.org/10.1016/j.lindif.2010.11.019

Yuan, S., Oshita, T., AbiGhannam, N., Dudo, A., Besley, J. C., & Koh, H. E. (2017). Two-way communication between scientists and the public: a view from science communication trainers in North America. *International Journal of Science Education, Part B*, *7*(4), 341–355. https://doi.org/10.1080/21548455.2017.1350789

Zimmerman, I., Baram-Tsabari, A., & Tal, T. (2024). Science communication objectives and actual practices of science news websites as a showcase for gaps between theory and practice. *JCOM*, *23*(01), A05. https://doi.org/10.22323/2.23010205

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Supplementary material

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Supplementary Material A: Survey on geoscience communication practices and perceptions
Supplementary Material B: Summary of the results of the demographic and descriptive analysis
Supplementary Material C: Detailed statistical results