

Geoscientists's views about science communication: predicting willingness to communicate geoscience

Joana Rodrigues¹, Cecília Castro², Elsa Costa e Silva³, Diamantino Insua Pereira¹

¹ Institute of Earth Sciences, Pole of the University of Minho, Braga, 4710-057, Portugal

5 ² Center of Mathematics, University of Minho, Braga, 4710-057, Portugal

³ Communication and Society Research Centre, University of Minho, Braga, 4710-057, Portugal

Correspondence to: Joana Rodrigues (joana225@gmail.com)

Abstract. The main barriers to science communication are common in different fields and they are widely identified in the literature. Studies focused on specific scientific communities framed science communication as an activity with the specificities of each context and field. In this study, we analysed geoscientists' representations and attitudes about communication to understand which factors can have significant impact on prediction of public engagement and that can explain the frequency/intensity of communication. The results pointed that factors such as professional experience, recognition by the institution, lack of financial support, personal satisfaction and geoscientific as an area of expertise, have a significant effect on their public engagement.

15 1 Introduction

Most scientists consider somehow important to communicate science (eg. Royal Society, 2006; Nielsen et al., 2007; Peters, 2013). It is not clear, however, whether this fact translates into effective communication (Jensen, 2011), as activities are mainly carried out as a 'goodwill exercise' (Neresini and Bucchi, 2011).

20 According to Burns et al (2003, p 191), science communication can be defined as the use of appropriate skills, media, activities and dialogue to produce personal responses to science, such as: awareness; enjoyment or other affective responses; interest, evidenced by voluntary engagement; opinions, forming, reforming and confirming science-related attitudes and understanding of contents, processes and social factors. It is considered an umbrella concept that includes several related terms such as 'dissemination', 'outreach', 'scientific literacy', 'popularization', 'informal education', 'public understanding of science', 'public awareness of science' or 'public engagement'. These concepts may have related goals but in fact, they are not
25 synonymous and each one reflects a specific context. This is the case of 'public engagement', a term that refers to the current understanding of the relationship between citizens and science. A relationship that should be a dialogical and participative process (Bucchi and Trench, 2016), but that it is still not always the case.

The type and nature of public engagement varies within specific communities and disciplines (Jensen and Croissant, 2007; Jensen, 2011; Kreimer et al., 2011; Johnson et al., 2014). Topics with greater popular visibility, public interest or increased
30 'social demand' such as medicine and health or climate, bring more attention to some areas than to others and give scientists different opportunities to engage with the public (Dunwoody et al., 2009; Jensen, 2011; Ivanova et al., 2013). For example, scientists who acknowledge the impact of their work tend to communicate more, such as nanoscientists, demonstrating greater sense of social responsibility (Dudo et al., 2014). Also, scientists who perceive the controversy of their research, as climate scientists (Entradas et al., 2019), or who understand the importance of communication for the well-being of society (Besley et

35 al., 2013). feel a bigger responsibility to communicate. On the other hand, some scientists may feel that their disciplines have a less political nature and, therefore, see less value in public engagement, thus discouraging communication- (Besley et al., 2013).

40 Generally, science communication intensity is higher in the social sciences and humanities areas (Kyvik, 2005; Jensen and Croissant, 2007; Torres-Albero et al., 2011; Jensen, 2011; Kreimer et al., 2011; Marchinkowski et al., 2014; Entradas and Bauer; 2017), despite natural sciences mobilising more practitioners in public events (Entradas and Bauer, 2017). Social Sciences and the Humanities engage more frequently with civic audiences and stakeholders, while Natural Sciences tend to address more often educational audiences (Entradas and Bauer, 2017). It is possible that natural science and technology scientists may engage less because lay public seem more interested in social, cultural or health topics (Bentley and Kyvik, 2011).

45 Natural and technology scientists experience more difficulties in making their research understandable when they communicate it (Bentley and Kyvik, 2011; Kyvik, 2005). Highly complex codes of the disciplines and difficulties of translation for non-experts are pointed out as barriers to communication (Bentley and Kyvik, 2011; Johnson et al., 2014). But, also, the behaviours and motivations differ; for example, astronomers participate regularly in engagement activities, what may be explained by astronomers' long tradition of outreach (Entradas and Bawer, 2019).

50 While previous studies showed that the majority of the scientific community, in general, was not involved in science communication (Jensen and Croissant, 2007), recent research presents evidence of higher levels of public engagement (eg. Rose et al., 2020). Also, specific communities such as climate scientists and astronomers have more often contact with lay audiences and are active communicators (Ivanova et al., 2013; Entradas et al., 2019, Entradas & Bauer, 2019). Jensen and Croissant (2007) followed the same community for several years and demonstrated that there is indeed an increasing trend in the number of activities. This trend may be mainly explained by external demands, related with the social impact of the topics (Jensen, 2011; Ivanova et al., 2013). For example, scientists in Spain do not see the need to communicate because there is a little demand for it (Torres-Albero et al., 2011).

60 Literature reveals a wide range of studies focused on specific scientific communities like geneticists (Mathews et al, 2005), nanoscientists (Corley et al., 2011; Dudo et al, 2014), astronomers (Entradas & Bauer, 2019; Anjos et al., 2021), biologists and physicists (Ecklund et al., 2012, Johnson et al., 2013), climate scientists (Entradas et al., 2019) or marine scientists (Pinto et al., 2018). A very first approach to study the geoscientists' community attitudes and practices was made by Liverman and Jaramillo (2011), under the scope of the Communicating Environmental Geosciences working group of the Commission for "Geoscience for Environmental Management" of the International Union of Geological Sciences (IUGS). That international study analysed environmental geoscientists's attitudes and experiences communicating science. The results of that study date back more than 10 years and comprise descriptive statistics, without advancing explanations about the reasons of these behaviours.

65 Geoscience communication is an emergent area that still needs a better formalization, regarding its interdisciplinary approach and its specific challenges. It can be summarized as a practice which seeks to communicate aspects of geoscience with a wider audience, with the aim of increasing attention, involvement and public discussion of geoscientific results, aspects of outreach, public engagement, participation or knowledge exchange (Illingworth et al 2018).

70 The main objective of this study is to maps and to better understand Portuguese geoscience community communication attitudes in order to address their specific needs, providing clues for institutions, and policy makers to improve communication. Our specific goals are: to analyse geoscientists' representations and attitudes about science communication (1), to recognize the motivations and obstacles towards science communication (2), to understand which indicators explain geoscientists

75 participation in public engagement (3), to identify the factors that drive to higher participation in those activities (4) and to
understand if the scientific nature/context² of geosciences influences scientists' attitudes towards communication (5).
This study not only intends to assess the Portuguese geoscience community but also to bring wide inputs for the international
community. These finds will contribute to develop a conceptual framework for geoscience communication research,
identifying the main challenges and opportunities.

80 Research questions:

(RS 1) what explains geoscientists' public engagement?

(RS 2) what explains the intensity of this public engagement?

2 Background

85 Previous studies on scientific communities identified several predictors of public engagement (eg. Poliakoff and Webb, 2007;
Dunwoody et al., 2009; Besley et al., 2013; Jensen 2011; Johnson et al., 2014), related with sociodemographic, context and
personal factors.

2.1 Sociodemographic factors

90 Literature shows that sociodemographic variables influence science communication performance, but sometimes with
inconsistent results. Some studies showed, for example, that women are more active (Andrews et al., 2005; Jensen, 2011;
Ecklund et al., 2012; Jonshon et al., 2014) and give more importance to communication activities. Other studies demonstrated
that men are more active (Crettaz von Roten, 2011) and they are more willing to communicate. More recent research concluded
that gender does not affect (Entradas and Bawer, 2019). Also, age can affect participation in public engagement (Jensen, 2011),
but together with gender and subfield, these factors seem to be considered minor predictors (Besley et al., 2013).

95 Formal training in science communication is considered a predictor (Dunwoody et al., 2009) and those who attends training
are more critical of their own performance (Clarkson et al., 2018). But most scientists have no training (Royal Society, 2006;
Entradas and Bawer, 2019; Ridgway et al., 2020) and geoscientists are no exception (Liverman 2009, Liverman and Jaramillo,
2011).

2.2 Context

Area of expertise

100 The contextual culture of each discipline influences the communication and type of activities (Johnson et al., 2014), as also
researchers' opinion about their field and its impact on society. As we discussed earlier, the differences between
communication practices of social and natural sciences and even between biology and physics have been studied. But when
studying a community of geoscientists it seems also pertinent to try to understand if there are patterns or relationships between
geosciences sub disciplines. The communication of geological hazards, an area with a large component of uncertainty and risk,
105 and the geological resources, with a huge impact on society and local communities, or tectonics, a field whose content and
practical applicability are far removed from the lay audiences, probably differ from each other.

For example, the abstract and not-human time scales of geoscience (see Bowring 2014) make public understanding difficult.
On the other hand, environmental topics tend to be discussed in a "battlefield" mode, discouraging many scientists from
engaging with the media (Boykoff, 2008). Also, many geoscience subjects are presented by the media mainly because of their
110 disaster side, journalists rarely approaching positive aspects of research or direct implications on people's lives (Liverman and
Jamarillo, 2011). Lack of strategic communication on topics with impacts on human health, for example regarding mining
wastes, produced negative effects on local populations (Di Giulio et al. 2008). Not only the social impacts but also the political,
cultural and economic orientations and the politicization of some subjects affects the will and way of communicating.

115 Public perception of their area of expertise

In general, scientists agree they have the moral duty to communicate, not only the results of their research but also social and ethical implications (Wellcome Trust 2000, Royal Society 2006). According to Liverman & Jaramillo (2011), environmental geoscientists tend to consider that their work is not too complex or uninteresting for lay audiences. They also recognize the implications of their work for society and decision-makers and their moral duty to communicate. The subdiscipline is also related with the scientist's sense of responsibility to communicate and with the perceived public interest and complexity of their area.

Professional experience

The professional experience and career position may have positive effects (Jensen and Croissant, 2007; Jensen et al., 2008; Jensen, 2011), even if science communication activities are not officially recognized for career progression. Among academic communities, senior researchers tend to be more active (Royal Society, 2006; Jensen, 2011; Kreimer et al., 2011; Torres Alberto, 2011; Entradas and Bawer 2019; Entradas et al., 2019). Also, the most academically productive researchers and with higher publication rankings engage more with public (Dunwoody and Ryan 1985; Jensen et al., 2008; Peters et al. 2008; Jensen, 2011; Bentley and Kyvik, 2011; Ivanova et al., 2013). These scientists tend to have more public visibility outside academic community (Jensen, 2011) and their status is positively correlated with [the](#) frequency of media engagement (Dunwoody et al., 2009).

Institution attitude

The context and attitudes of the institution influence the intensity of communication (Dunwoody and Ryan, 1985; Marchinkowski et al., 2014). Scientific institutions seem to be more and more committed with public communication and performance indicators might prove their support, even so it is not considered an essential element (Neresini and Bucchi, 2011). Scientific careers and academic systems are still focused on research productivity and lack of encouragement and support from institution may be a demotivating factor for public engagement (Andrews et al., 2005; Ecklund et al., 2012; Shanley and Lopez, 2009; Rose et al., 2020). More recognition, rewards, encouragement from department heads would foster science communication activities (Royal Society, 2006).

Barriers

Several barriers to public engagement have been pointed out by different scientific communities. Quite common are the lack of time (Pearson et al., 1997; Wellcome Trust, 2000; Andrews et al., 2005; Mathews et al., 2005; Royal Society, 2006; Nielsen et al., 2007; Poliakoff and Webb, 2007; Shanley and Lopez, 2009; Pinto et al., 2018; Ridgway et al., 2020), lack of financial support (Poliakoff and Webb, 2007; Shanley and Lopez, 2009; Pinto et al., 2018) or the lack of skills and training to communicate (Mathews et al., 2005; Shanley and Lopez, 2009), as discussed before.

The audience is also often identified as a barrier. Scientists see the public as a homogeneous group, irrational and misguided (Royal Society, 2006; Cook et al., 2004; Davies, 2008) and their seemingly lack of knowledge and interest discourages engagement (Wellcome Trust, 2000; Blok et al., 2008; Besley and Tanner, 2011; Ecklund et al., 2012; Pinto et al., 2018; Anjos et al., 2021), [which is](#) even more common in highly codified disciplines (as mathematics or chemistry) (Bentley and Kyvik, 2011).

In some cases, scientists feel that public engagement can cause negative opinion in their peers and have a negative impact in their career for making science too accessible and causing perceived reputational damages (Mathews et al., 2005; Royal Society, 2006; Jensen et al., 2008; Ecklund et al., 2011, Johnson et al., 2014).

The perception that scientists' visibility and frequency of media interaction might be inverse to their scientific ability and research is known as 'Sagan Effect', named after the astronomer and communicator Carl Sagan (Russo, 2010; Martinez-Conde, 2016). More recent studies show that peer critic opinions do not matter (Entradas and Bawer, 2018; Ridgway et al., 2020).

The [relationship](#) with [the](#) media has been always controversial (eg. Dunwoody and Ryan, 1985; Harz and Chappell, 1998; Nielsen et al., 2007; Corley et al., 2011; Anjos et al., 2021), even if the paradigm seems to be progressively changing (Peter et al., 2008; Dunwoody et al., 2009; Ivanova et al., 2013). Scientists report critical opinion but positive experiences with journalists (Peters et al., 2008; Besley and Tanner, 2011), however they underline misrepresentation of scientific content by

journalists as an obstacle to communication (Blok et al., 2008; Young and Matthews, 2007; Hartz and Chappell, 1997; Mathews et al., 2005; Davies, 2008).

165 2.3 Personal factors

Self-perceived competence (self-efficacy)

170 Scientist's perception of [fr](#) their own skills and ability to communicate tends to have a positive impact on the intention to communicate and on their performance (Wellcome Trust, 2000; Gascoigne and Metcalfe, 1997; Poliakoff and Webb 2007; Dunwoody et al., 2009; Ecklund et al., 2012). In general, scientists feel prepared to communicate (Wellcome Trust, 2000; Royal Society, 2006), some even feel overconfidence (Rose et al., 2020). [However, they feel less confident](#) when it regards social and ethical implications (Royal Society, 2006).

The lack of communication skills and training can be considered [a barrier to participate](#) (Dunwoody and Ryan, 1985; Mathews et al., 2005; Poliakoff & Webb, 2007; Pinto et al., 2018) or not (Ridgway et al., 2020).

175 Personal satisfaction

Perception of personal performance may also provide indication about the attitude towards communication. Generally, scientists would like to spend more time with public engagement (Royal Society, 2006; Nielsen et al., 2007, Bentley and Kyvik, 2011; Liverman and Jaramillo, 2011), probably because it is not their main priority and they understand its benefits. Positive experiences and personal satisfaction [is positively related to](#) the intention to communicate (Andrews et al., 2005; 180 Dunwoody et al., 2009; Entradas et al., 2019).

3. Data collection

To answer the research questions, (RS 1) what explains geoscientists' public engagement and (RS 2) what explains the intensity of this public engagement, a quantitative methodology was selected, with an attitude-based questionnaire, built for the purpose of this work [and](#) considering the factors [willingness](#) and barriers to communication reviewed in the literature.

185 The data was collected through an online survey applied by self-administered questionnaire, through Google Forms, between June and July 2020, after a pilot test with 10 respondents.

The questionnaire consists of 47 questions (subdivided into 161 indicators) with an optional comment box. It is divided in three groups: demographic profile (a), experiences and practices (b) and representations (c) on science communication. It included closed-ended questions (multiple-choice, dichotomous, Likert scales, matrix, and ranking) and open-ended questions 190 about geoscience topics and subjects. Since the survey applied is very extensive, with too many questions and indicators, we will focus on the present study on the data collected about the perceptions, analysing representations, beliefs, attitudes, preferences, motivations and expectations, in a total of [29-30](#) indicators.

[An a-priori factorisation and a selection of the factors was performed under a strategic perspective drawn from the literature review and based on previous questionnaires such as Hartz and Chappell \(1997\), Wellcome Trust \(2000\), Royal Society \(2006\) and Liverman & Jaramillo \(2011\).](#)

195 The complete questionnaire is available in the supplementary material [A](#). The results referring to the [29-30](#) indicators studied in the scope of this work are also available [in supplementary material D](#).

3.1. Data set

200 There is no official data on the number of geoscientists in Portugal, so a broad distribution of questionnaires was made by e-mail and social media. Scientific and professional associations and networks, research centres and university departments in Portugal were contacted to cooperate [in the dissemination of](#) the questionnaire among their members. It was also advertised in social media, in science communication and geoscience pages and groups. Despite the respondents being from different

sociodemographic groups, different professional categories and different fields of geosciences, the inference must be cautious since there is no guarantee of representativeness of the population under study. The data set consists on geoscience professionals and postgraduate students, developing their work in Portugal. A total of 179 valid responses was collected. As science communication practitioners are not only researchers and the academic community, data set also includes other professional. Among the surveyed geoscientists there were technical professionals (28%), university professors (20%), school teachers (18%), researchers (17%), postgraduate students (11%) and even science communicators (4%).

The surveyed geoscientists were 52% females, 56% were more than 41 years old, 40% have a PhD and 42% a Master degree. Regarding their degree area, the majority studied Geology (70%), followed by Biology and Geology / Environmental Sciences / Environmental Education (16%), and other areas such as Geological Engineering / Mine Engineering, Biology, Geophysics / Meteorology / Oceanography / Physics and Geography / Aerospace Engineering. The sample slightly overrepresented scientists with Geology degree (70%), with only 30% [of geoscientists from](#) the other degrees.

Regarding geographic distribution, responses were collected in all regions of Portugal, with a greater justifiable representation of areas with higher population density and greater concentration of scientific institutions (universities, research centres, science centres and Geoparks).

3.2 Methodology

[Data was analysed by using SPSS, version 25.0 \(IBM Statistics\) and R, version 4.2.0.](#) In addition to chi-square tests and Fisher's exact tests, used to test the independence between categorical variables, the statistical methodology consisted in the use of generalized linear models, with an explanatory objective (McCullagh and Nelder, 1989), since the main interest of this paper was to identify a set of features that can explain public engagement and the intensity of communication in science. In this work, we consider a result statistically significant if the p-value associated with the test statistic is $p < 0.05$ and statistically highly significant if the p-value is $p < 0.001$.

The technique of multinomial logistic regression was used to model categorical response variables. Through this model, factors affecting the class of the categories can be determined simultaneously. The multinomial response variable of intensity of public engagement consists of three categories: very active, active and inactive. [An overview through the model is available as supplementary material B.](#)

4. Results and discussion

Descriptive analysis of the results summarize the characteristics of the data set [\(supplementary material C\)](#). Regarding geoscientific areas, all the experts in External Geodynamics and Palaeontology and Geoconservation and Geotourism reported public engagement activities. Only 5.6% of the experts in Geological and Energy Resources did not reported any activity. Also, 25% of the experts in History and Education or Environmental Geology and Environment and Engineering Geology reported no activity.

Concerning the institution attitude, 14,5% of respondents admit that their institution does not value communication activities, against 40,8% who consider that the institution gives some importance and 44,7% [who say it](#) that gives high value. These results show that the majority of the institutions have a [perceived](#) positive attitude towards communication that encourages geoscientist to engage with the public.

Concerning the perception about their geoscientific area, the majority (60%) does not think it is too complex to lay audiences and only 23% [consider it to be](#) too intricate. For, 36% this is an obstacle to communication. Most of them (79%) consider that their area is interesting for non-experts and 85% admit that their work has implications for society and/or policy makers. The vast majority (90%) believes that scientists have a moral duty to engage with the non-expert public about the social and ethical implications of their work.

250 Regarding the obstacles to science communication, lack of financial support (87%) and lack of time (80%) are considered the biggest barriers. The majority (85%) does not think these activities make science less rigorous, 64% does not fear creating misunderstandings and generating controversy, but 75% believe that journalists' misrepresentation of scientific content is a barrier. This factor may partly explain, together with lack of opportunities, why the great majority of respondents reported none or rare contact with journalists or science journalists.

As for the audience's attitude, respondents believe that the public's lack of interest (64%) and lack of knowledge (61%) may be a constraint, but 64% does not see the complexity of their work area as an obstacle.

255 Regarding specific skills to communicate, only 56% agrees that lack of preparation/training can be an obstacle and 37% points out that discomfort in communicating with lay audiences can be a barrier. For 43% of the geoscientists, the negative opinion of their peers seems to somehow constrain.

260 Analysing the self-perceived competence, only 6% of the surveyed geoscientists admitted they do not have the necessary skills to communicate science. The vast majority feels prepared to communicate, with more than half (52%) being truly confident. Regarding more specific skills to communicate about the social and ethical implications of science, 25% recognized they do not feel prepared. At the same time, as seen above, almost half (44%) do not agree that lack of preparation or training may be an obstacle for effective communication.

265 Concerning the personal satisfaction, most of the respondents reported positive experiences and only around 1/4 feel dissatisfied. Almost half of the geoscientists (47%) think the number of communication activities they do annually is good and 12% think it is very good. However, an expressive amount of 40% thinks the number is reduced. For the vast majority of respondents (86%) it is gratifying to engage non-specialist audiences in science and 92% reported they find somehow important to find time to engage with non-expert audiences, demonstrating that geoscientists are aware of the importance of communication and they are interested in doing such activities.

270

4.1 Factors associated geoscientists' public engagement

In a first moment, we studied the influence that each isolated factor has on the response, regardless any of the others. Results from Chi-square tests (Table 1) demonstrated the relevant context and personal factors influencing the geoscientists' public engagement. No positive association was found with sociodemographic factors such as age or gender.

275

| Factors | Pearson Statistics and p-value | Conclusion |
|---|------------------------------------|---|
| Area of expertise | $X^2 = 19.048, df = 10, p = 0.040$ | Experts in Geological and Energy Resources tend to have more activity |
| Professional experience | $X^2 = 15.078, df = 6, p = 0.020$ | Who has more than 20 years of experience tends to have more activity |
| Institution attitude | $X^2 = 26.135, df = 4, p < 0.001$ | Who perceives more recognition tend to have more activity |
| Perceived implications for society | $X^2 = 12.636, df = 4, p = 0.013$ | Who agrees more that its work has implications for society tends to have more activity |
| Lack of financial support | $X^2 = 12.886, df = 4, p = 0.012$ | Who agrees more that lack of financial support is an obstacle tends to have more activity |
| Perceived complexity of their geoscientific subject | $X^2 = 11.920, df = 4, p = 0.018$ | Who doesn't agree that the complexity of their geoscientific subject is an obstacle tends to have more activity |

| | | |
|-------------------------------------|-----------------------------------|--|
| Self-perceived competence | $X^2 = 30.450, df = 4, p < 0.001$ | Who feels more confidence in its skills tends to have more activity |
| Perception of the public engagement | $X^2 = 41.183, df = 4, p < 0.001$ | Who thinks that performs a reasonable number of activities tends to have more activity |
| Personal satisfaction | $X^2 = 33.239, df = 4, < 0.001$ | Who reports positive experiences tends to have more activity |

Table 1 - Results from chi-square tests

280

Regarding to RS 1 ‘what explains geoscientists’ public engagement’ we [thus](#) found that the factors area of expertise, professional experience, institution attitude, perceptions about the implications for society, lack of financial support, perceived complexity of their geoscientific subject the self-perceived competence, the perception of the public engagement and personal satisfaction, each have a significant effect on the response.

285 4.2 Factors explaining the intensity of this public engagement

To answer our RS 2, we used the approach of multinomial logistic analysis model that allows the selection of predictors that, together, have a significant effect on the dependent variable intensity of communication-

290

Participants were asked how many science communication activities had they carried out in the previous year. As no prior detailed explanation of 'science communication activities' was given, each respondent reported the activities they assume as such and which they consciously carry out as science communication.

The frequency/intensity variable [was then](#) organized into three categories: ‘inactive’ communicators, who reported not having carried out any activity in the last year (11.5%), ‘active’ that performed between 1 and 3 activities (35.3%) and ‘very active’ that reported more than 4 activities in the last year (53.2%). The reference class is ‘very active’.

295

Multinomial logistic analysis began with the selection of important predictor variables using several selection feature techniques, including step-by-step forward and backward based on the log-likelihood of models. Among all possible predictors, the best model (in terms of goodness of fit, based on the model's log-likelihood) includes the predictors: area of expertise, professional experience, institution attitude, lack of financial and personal satisfaction.

300

The goodness-of-fit indicator Nagelkerk's R² value is 0.597. The confusion matrix (Table 2) shows that the overall percentage of correct ratings is 72.4%. Regarding the percentage of correct classifications, by category, the highest, 85.5%, is obtained in the category ‘very active’ and the lowest in the category, ‘inactive’ (55.6%). It is possible to conclude the model has a good predictive ability. The coefficients table is available on the supplementary material [B](#).

305

| Classification | Predicted | | | Percent Correct |
|----------------|-----------|-----|----|-----------------|
| | none | 1-3 | >4 | |
| Observed | | | | |
| none | 10 | 4 | 4 | 55,6% |
| 1-3 | 2 | 32 | 21 | 58,2% |
| >4 | 3 | 9 | 71 | 85,5% |

| | | | | |
|-----------------|------|-------|-------|-------|
| Percent Correct | 9,6% | 28,8% | 61,5% | 72,4% |
|-----------------|------|-------|-------|-------|

Table 2 - Confusion matrix

310 Comparing ‘inactive’ with ‘very active’ (more than 4 activities), results show that the probability of not making any
 | communication increases significantly in individuals with 5 to 10 years of experience, when compared to those with more than
 20 years. The probability of engaging into public activities increases significantly in those whose institution appreciates their
 efforts. Therefore, if the institution values public engagement, the probability of an individual not making any communication
 decreases. For respondents with unsatisfactory experiences with public engagement, the probability of not making any
 315 communication increases. For geoscientists from areas of expertise like Geological and Energy Resources the probability of
 making activities increases.

320 Taking as reference the class ‘very active’ it is possible to conclude that the risk factors, i.e. increasing the probability of being
 ‘inactive’, are individuals with 5-10 years of experience and with unsatisfactory communication experiences. On the other
 hand, the probability of being ‘active’ (performing between 1–3 activities) increases for individuals those whose institution
 moderately or highly appreciates their efforts. The probability decreases for individuals with less than 5 years of experience
 and for those who do not see lack of financial support as an obstacle-

Therefore, it is possible to conclude that having more than 20 years of experience, being in an institution who recognizes
 efforts in public engagement and working in Geological and Energy Resources areas fosters the increase of the number of
 communication activities per year, while previous unsatisfactory communication experiences are a risk factor.

325 For the RS 2 ‘what explains geoscientists’ public engagement’ we identified the following factors: the intensity of
 geoscientists’ public engagement may be explained by the area of expertise, professional experience, institution attitude, lack
 of financial support and personal satisfaction.

330 Geoscientists from areas of expertise like Geological and Energy Resources, External Geodynamics and Palaeontology,
 Geoconservation and Geotourism are more likely to be active or very active in communication activities, than those from areas
 such as History and Education or Environmental Geology and Environment and Engineering Geology. On the other hand, the
 lack of support and the few years of experience are factors that may induce low frequency of science communication activities.

335 Despite the fact that, nowadays, scientific institutions seem to be more aware of the importance of public engagement,
 promoting and supporting initiatives and involving scientists, funding and career progressions still depend on research
 rankings. Many geoscientific institutions in Portugal promote the participation of their professionals in events such as Open
 Days, European Researchers Night, Living Science in Summer and at the School. Also, research projects funding requires
 work packages on the dissemination of results and outreach. However, all these endeavours are not considered on formal
 performance evaluation. Beside encouragement and financial resources, geoscientists could feel more committed to
 communicate with the public with formal recognition, logistical support, dedicated time and training.

340 On the other hand, we also concluded that less experienced professionals tend to engage less with the public. These results can
 be explained with the same argument of research rankings and lack of time, more crucial in early carriers. Also, the lack of
 public communication experience may deter geoscientists. Senior scientists with longer carriers, more recognized experience
 and visibility may also receive more demands.

345 As proved for other communities, we concluded that geoscientists with previous unsatisfactory experiences tend to
 communicate less. Lack of training, lack of support, non-expected impacts or so many other reasons can explain the
 dissatisfaction. This research focuses on scientists rather on audience, so we can only conclude about the intensity of public
 engagement and not about quality or impact of communication. A solution to overcome this barrier would be to follow closer
 these professionals, understand their difficulties and support them in overcoming them.

350 Regarding the area of expertise, despite dealing with complex and abstract processes and time scale, scientists from areas such
 External Geodynamics and Palaeontology, tend to communicate more. Fossils (including dinosaurs) and landscapes may be
 difficult to understand but can be more appealing for non-expert audience.

Geoconservation and Geotourism experts work with geological heritage, an appealing topic and usually have public communication included in their duties. Some of them work in institutions like museums, science centres or geoparks and tend to be more motivated. Geological and Energy Resources are topics currently with high media visibility and social debates demanding geoscientists to engage more with public.

355 History and Education experts seem to engage less probably because these areas are extremely applied.
At last, geoscientists from areas such Environmental Geology and Environment and Engineering Geology tend to communicate less. This result could not have been expected, as these areas include topics such as climate change, soil and water contamination, topics with great social impact, on people's health and life. On the other hand, these areas have great visibility in media and public debate, discussions are very polarized and politicized and very often geoscientist face uncomfortable experiences. These results show that communication attitudes also depend on area of expertise. Interventions to foster public engagement among geoscientists should be target to different areas of expertise. Areas with more public visibility and polarization could benefit from targeted training, addressing the specific challenges they face and working together with social and human scientists. Training for geoscience graduation students, designed to answer specific challenges such as risk and emergency response, proved to be very effective improving communication skills (Dohaney et al., 2015).

365

5. Conclusions

The results of our study show that the majority of the surveyed geoscientists have positive impressions regarding public engagement, being motivated, feeling comfortable and prepared to communicate. The main outcomes of the research confirm the patterns of scientists from other areas previously studied.

370 We concluded that public engagement may be explained by context factors such as area of expertise, professional experience, institution attitude, perceptions about the implications for society, lack of financial support and perceived complexity of their geoscientific subject and personal factors as the self-perceived competence, personal satisfaction and the perception of the public engagement.

375 Furthermore, we concluded that what really matters for the intensity of this public engagement are the context factors, like the area of expertise, personal experience, institution attitude, lack of financial support, and personal factors such as satisfaction. These should be the main factors to be considered when designing policies to support and promote public engagement, as they identify specific aspects that are more likely to lead to foster results.

380 The findings discussed above can support the development of strategies and recommendations that will contribute to overcome the constraints and lead to a more effective communication between scientists and society. Further research on geoscientist's representations would allow to understand the relation between perceptions and their practices.

385 Regarding the limitations of this research, we recognize a possible sampling bias. Firstly, it is a set of data that may not be representative of the entire population since the respondents were self-selected. Although the questionnaire was destined to both communicators and non-communicators, we assume the possibility that scientists less aware of communication may have responded less, leading to an overrepresentation of those who communicate. Also, in surveys like this in which people are asked to provide personal opinions and report personal practices, it is necessary to take into account that people may be led to answer according to socially desirable ideas. To try to reduce this bias and obtain more truthful answers, participants were informed that their identities were protected and the results would be appropriately anonymized. At the same time, online self-administered questionnaires, without the presence of other people, as it is the case, also contribute to reduce social desirability bias.

390 More robust results could be possible with a larger sample, for example analysing an international community or following the community for an extended period of time (e.g. Jensen & Croissant 2007). Also, complementary interviews could bring additional qualitative data. Despite these constraints, the sociodemographic heterogeneity of the data set, as well as the comparison of our outcomes with previous studies, reinforces the confidence in the results.

395

Competing interests

The authors have declared that there are no competing interests.

Ethical statement

400 The work performed in this study is original, reflects the authors' view and it does not engage in any form of malicious harm to other persons. The participation in the survey was voluntary and anonymous.

Data availability

405 The survey and the statistical results are available in supplementary material.

Author contribution

JR, ES, DP planned the research; JR collected the data; CC and JR analysed the data, JR prepared the manuscript draft, JR, CC, ES, DP contributed to the writing, review, and editing.

410 Acknowledgements

Authors thank to referees for their careful reading and for their constructive suggestions.

This work is supported by national funding awarded by FCT - Foundation for Science and Technology, I.P., projects UIDB/04683/2020 and UIDP/04683/2020.

References

- 415 Andrews, E., Weaver, A., Hanley, D., Shamatha, J., and Melton, G.: Scientists and public outreach: Participation, motivations, and impediments, *J Geosci Educ*, 53(3), 281-293, [doi:10.5408/1089-9995-53.3.281](https://doi.org/10.5408/1089-9995-53.3.281), 2005.
- Anjos, S., Russo, P., and Carvalho, A.: Communicating astronomy with the public: perspectives of an international community of practice, *J Sci Commun*, 20(3), A11, [doi:10.22323/2.20030211](https://doi.org/10.22323/2.20030211), 2021.
- 420 Bentley, P. and Kyvik, S.: Academic staff and public communication: a survey of popular science publishing across 13 countries, *Public Underst Sci*, 20(1), 48-63, [doi:10.1177/0963662510384461](https://doi.org/10.1177/0963662510384461), 2011.
- Besley, J. C., and Tanner, A. H.: What science communication scholars think about training scientists to communicate, *Sci Commun*, 33(2), 239-263, [doi:10.1177/1075547010386972](https://doi.org/10.1177/1075547010386972), 2011.
- Besley, J. C., Oh, S. H., and Nisbet, M.: Predicting scientists' participation in public life, *Public Underst of Sci*, 22(8), 971-987, [doi:10.1177/0963662512459315](https://doi.org/10.1177/0963662512459315), 2013.

- 425 Blok, A., Jensen, M., and Kaltoft, P.: Social identities and risk: expert and lay imaginations on pesticide use, *Public Underst Sci*, 17(2), 189-209, [doi:10.1177/0963662506070176](https://doi.org/10.1177/0963662506070176), 2008.
- Bowring, S. A.: Perceptions of Time Matter: The Importance of Geoscience Outreach, in: *Geoscience Research and Outreach. Innovations in Science Education and Technology 21*, edited by Tong V., Springer, Dordrecht, 11-15, [doi:10.1007/978-94-007-6943-4_2](https://doi.org/10.1007/978-94-007-6943-4_2), 2014.
- 430 Boykoff, M. T.: Media and scientific communication: a case of climate change, in: *Communicating Environmental Geoscience*, Geological Society, Special Publications, 305(1), edited by Liverman, D.G.E., Pereira, C.P., and Marker, B., London, 11-18. doi.org/10.1144/SP305.3, 2008.
- Bucchi, M. and Trench, B.: Science communication and science in society: A conceptual review in ten keywords. *Tecnoscienza - Italian Journal of Science and Technology Studies* 7(2), 151-168. <http://www.tecnoscienza.net/index.php/tsj/article/view/277/181>, 2016
- 435 Clarkson, M. D., Houghton, J., Chen, W., and Rohde, J.: Speaking about science: a student-led training program improves graduate students' skills in public communication, *J Sci Commun*, 17(2), A05, [doi:10.22323/2.17020205](https://doi.org/10.22323/2.17020205), 2018.
- Cook, G., Pieri, E., and Robbins, P. T.: 'The scientists think and the public feels': Expert perceptions of the discourse of GM food, *Discourse Soc*, 15(4), 433-449, [doi:10.1177/0957926504043708](https://doi.org/10.1177/0957926504043708), 2004.
- 440 Corley, E.A., Kim, Y., and Scheufele, D.A.: Leading US nano-scientists' perceptions about media coverage and the public communication of scientific research findings, *J Nanopart Res*, 13, 7041-7055, [doi:10.1007/s11051-011-0617-3](https://doi.org/10.1007/s11051-011-0617-3), 2011.
- Crettaz von Roten, F.: Gender differences in scientists' public outreach and engagement activities, *Sci Commun*, 33(1), 52-75, [doi:10.1177/1075547010378658](https://doi.org/10.1177/1075547010378658), 2011.
- Davies, S. R.: Constructing communication: Talking to scientists about talking to the public, *Sci Commun*, 29(4), 413-434, [doi:10.1177/1075547008316222](https://doi.org/10.1177/1075547008316222), 2008.
- 445 Di Giulio, G. M., Pereira, N. M., and de Figueiredo, B. R.: Lead contamination, the media and risk communication: a case study from the Ribeira Valley, Brazil, in: *Communicating Environmental Geoscience*, Geological Society, Special Publications, 305(1), edited by Liverman, D.G.E., Pereira, C.P., and Marker, B., London, 63-74. [doi:10.1144/SP305.7](https://doi.org/10.1144/SP305.7), 2008.
- Dudo, A., Kahlor, L., AbiGhannam, N., Lazard, A., and Liang, M. C.: An analysis of nanoscientists as public communicators, *Nat Nanotechnol*, 9(10), 841-844, [doi:10.1038/nnano.2014.194](https://doi.org/10.1038/nnano.2014.194), 2014.
- 450 Dunwoody, S. and Ryan, M.: Scientific barriers to the popularization of science in the mass media, *J Commun*, 35(1), 26-42, [doi:10.1111/j.1460-2466.1985.tb01882.x](https://doi.org/10.1111/j.1460-2466.1985.tb01882.x), 1985.
- Dunwoody, S., Brossard, D., and Dudo, A.: Socialization or rewards? Predicting U.S. scientist-media interactions, *J Mass Commun Q*, 86(2), 299-314, [doi:10.1177/107769900908600203](https://doi.org/10.1177/107769900908600203), 2009.
- 455 Dohaney, J., Brogt, E., Kennedy, B., Wilson, T. M., and Lindsay, J. M.: Training in crisis communication and volcanic eruption forecasting: design and evaluation of an authentic role-play simulation, *J Appl. Volcanol*, 4, 12, [doi:10.1186/s13617-015-0030-1](https://doi.org/10.1186/s13617-015-0030-1), 2015.
- Ecklund, E. H., James, S. A., and Lincoln, A. E.: How Academic Biologists and Physicists View Science Outreach, *PLoS ONE*, 7(5), e36240, [doi:10.1371/journal.pone.0036240](https://doi.org/10.1371/journal.pone.0036240), 2012.
- 460 Entradas, M., Marcelino, J., Bauer, M. W., and Lewenstein, B.: Public communication by climate scientists: what, with whom and why?, *Clim Change*, 154, 69-85, [doi:10.1007/s10584-019-02414-9](https://doi.org/10.1007/s10584-019-02414-9), 2019.
- Entradas, M. and Bauer, M. M.: Mobilisation for public engagement: benchmarking the practices of research institutes, *Public Underst Sci*, 26(7), 771-788, [doi:10.1177/0963662516633834](https://doi.org/10.1177/0963662516633834), 2017.
- Entradas, M. and Bauer, M. W.: Bustling public communication by astronomers around the world driven by personal and contextual factors, *Nat Astron*, 3(2), 183, [doi:10.1038/s41550-018-0633-7](https://doi.org/10.1038/s41550-018-0633-7), 2019.
- 465

- Gascoigne, T. and Metcalfe, J.: Incentives and impediments to scientists communicating through the media, *Sci Commun*, 18(3), 265-282, [doi:10.1177/1075547097018003005](https://doi.org/10.1177/1075547097018003005), 1997.
- 470 Hartz, J. and Chappell, R., *Worlds Apart: how the distance between science and journalism threatens America's future, Analyzing Current Attitudes, First Amendment Center*, <https://www.freedomforuminstitute.org/wp-content/uploads/2016/10/worldsapart.pdf>, (last access: 18 June 2022), pp. 178, 1998
- Ivanova, A., Schäfer, M. S., Schlichting, I., and Schmidt, A.: Is there a medialization of climate science? Results from a survey of German climate scientists, *Sci Commun*, 35(5), 626–653, [doi:10.1177/1075547012475226](https://doi.org/10.1177/1075547012475226), 2013.
- Jensen, P.: A statistical picture of popularization activities and their evolutions in France, *Public Underst Sci*, 20(1), 26–36, [doi:10.1177/0963662510383632](https://doi.org/10.1177/0963662510383632), 2011.
- 475 Jensen, P. and Croissant, Y.: CNRS researchers' popularization activities: a progress report, *J Sci Commun*, 6 (3), [doi:10.22323/2.06030201](https://doi.org/10.22323/2.06030201), 2007.
- Jensen, P., Rouquier, J. B., Kreimer, P., and Croissant, Y.: Scientists who engage with society perform better academically, *Sci Public Policy*, 35(7), 527-541, [doi:10.3152/030234208X329130](https://doi.org/10.3152/030234208X329130), 2008.
- 480 Johnson, D. R., Ecklund, E. H., and Lincoln, A. E.: Narratives of science outreach in elite contexts of academic science, *Sci Commun*, 36(1), 81-105, [doi:10.1177/1075547013499142](https://doi.org/10.1177/1075547013499142), 2014.
- Kreimer, P., Levin, L., and Jensen, P.: 'Popularization by argentine researchers: the activities and motivations of CONICET scientists', *Public Underst Sci*, 20(1), 37–47, [doi:10.1177/0963662510383924](https://doi.org/10.1177/0963662510383924), 2011.
- Kyvik, S.: Popular science publishing and contributions to public discourse among university faculty, *Sci Commun*, 26(3), 288-311, [doi:10.1177/1075547004273022](https://doi.org/10.1177/1075547004273022), 2005.
- 485 Liverman, D.: *Communicating Geological Hazards: Educating, Training and Assisting Geoscientists in Communication Skills*, in: *Geophysical Hazards. Minimizing Risk, Maximizing Awareness*, edited by Beer, T., Springer, Dordrecht., 41–55, [doi:10.1007/978-90-481-3236-2_4](https://doi.org/10.1007/978-90-481-3236-2_4), 2009.
- Liverman, D. and Jaramillo, M.: *Communicating Environmental Geoscience – An International Survey*, *Episodes*, 34, 25–31, [doi:10.18814/epiugs/2011/v34i1/004](https://doi.org/10.18814/epiugs/2011/v34i1/004), 2011.
- 490 Marcinkowski, F., Kohring, M., Furst, S., and Friedrichsmeier, A.: Organizational influence on scientists' efforts to go public: an empirical investigation, *Sci Commun*, 36(1), 56–80, [doi:10.1177/1075547013494022](https://doi.org/10.1177/1075547013494022), 2014.
- Martinez-Conde, S.: Has contemporary academia outgrown the Carl Sagan effect?, *J Neurosci*, 36(7), 2077-2082, [doi:10.1523/JNEUROSCI.0086-16.2016](https://doi.org/10.1523/JNEUROSCI.0086-16.2016), 2016.
- 495 Mathews, D. J., Kalfoglou, A., and Hudson, K.: Geneticists' views on science policy formation and public outreach, *American J Med Genet*, 137A(2), 161-169, [doi:10.1002/ajmg.a.30849](https://doi.org/10.1002/ajmg.a.30849), 2005.
- McCullagh, P. and Nelder, J. A.: *Generalized Linear Models, Monographs on Statistics and Applied Probability*, 37, 2nd edition, Chapman and Hall, London, 1989.
- Neresini, F., and Bucchi, M.: Which indicators for the new public engagement activities? An exploratory study of European research institutions, *Public Underst Sci*, 20(1), 64-79, [doi:10.1177/0963662510388363](https://doi.org/10.1177/0963662510388363), 2011.
- 500 Nielsen, K., Kjaer, C. R., and Dahlgaard, J.: Scientists and science communication: a Danish survey, *J Sci Commun*, 6(1), A01, [doi:10.22323/2.06010201](https://doi.org/10.22323/2.06010201), 2007.
- Pearson, G., Pringle, S. M., and Thomas, J. N.: Scientists and the public understanding of science, *Public Underst Sci*, 6(3), 279, [doi:10.1088/0963-6625/6/3/006](https://doi.org/10.1088/0963-6625/6/3/006), 1997.
- 505 Peters, H. P. (2013). Gap between science and media revisited: Scientists as public communicators. *Proceedings of the National Academy of Sciences*, 110(3), 14102-14109. <https://doi.org/10.1073/pnas.1212745110>

- Peters, H. P., Brossard, D., de Cheveigné, S., Dunwoody, S., Kalfass, M., Miller, S. and Tsuchida, S.: Science communication: interactions with the mass media, *Science*, 321(5886), 204–205, [doi:10.1126/science.1157780](https://doi.org/10.1126/science.1157780), 2008.
- 510 Pinto, B. M., Costa, J. L., and Cabral, H. N.: How do science communication practitioners view scientists and audiences in relation to public engagement activities? A research note concerning the marine sciences in Portugal, *Bull Sci Technol Soc*, 37(3), 159-166, [doi:10.1177/0270467618819683](https://doi.org/10.1177/0270467618819683), 2018.
- Poliakoff, E. and Webb, T. L.: What factors predict scientists' intentions to participate in public engagement of science activities?, *Sci Commun*, 29(2), 242–263, [doi:10.1177/1075547007308009](https://doi.org/10.1177/1075547007308009), 2007.
- 515 Ridgway, A., Milani, E., Weitkamp, E., and Wilkinson, C.: Report on the Working Practices, Motivations and Challenges of those Engaged in Science Communication. European Commission repository and Zenodo: European Commission. <https://uwe-repository.worktribe.com/output/6017685>. (last access: 18 June 2022), 59 pp., 2020.
- Wellcome Trust: The Role of Scientists in Public Debate, London, Mori, https://wellcome.org/sites/default/files/wtd003425_0.pdf (last access: 18 June 2022), 50 pp., 2000.
- Rose, K. M., Markowitz, E. M., and Brossard, D.: Scientists' incentives and attitudes toward public communication, *Proc Natl Acad Sci U S A*, 117(3), 1274-1276, [doi:10.1073/pnas.1916740117](https://doi.org/10.1073/pnas.1916740117), 2020.
- 520 Royal Society: Survey of factors affecting science communication by scientists and engineers excellence in science, London, Research Councils UK, Wellcome Trust, https://royalsociety.org/~media/Royal_Society_Content/policy/publications/2006/1111111395.pdf (last access: 18 June 2022), 45 pp., 2006
- Russo, G.: Outreach: Meet the press, *Nature*, 468, 465–467, [doi:10.1038/nj7322-465a](https://doi.org/10.1038/nj7322-465a), 2010.
- 525 Shanley, P. and López, C.: Out of the loop: why research rarely reaches policy makers and the public and what can be done, *Biotropica*, 41(5), 535-544, [doi:10.1111/j.1744-7429.2009.00561.x](https://doi.org/10.1111/j.1744-7429.2009.00561.x), 2010.
- Torres-Albero, C., Fernández-Esquinas, M., Rey-Rocha, J., and Martín-Sempere, M. J.: Dissemination practices in the Spanish research system: scientists trapped in a golden cage, *Public Underst Sci*, 20(1), 12-25, [doi:10.1177/0963662510382361](https://doi.org/10.1177/0963662510382361), 2011.
- 530 Young, N. and Matthews, R.: Experts' understanding of the public: Knowledge control in a risk controversy, *Public Underst Sci*, 16(2), 123-144, [doi:10.1177/0963662507060586](https://doi.org/10.1177/0963662507060586), 2007.
- Wellcome Trust: The Role of Scientists in Public Debate, London, Mori, https://wellcome.org/sites/default/files/wtd003425_0.pdf (last access: 18 June 2022), 50 pp., 2000.