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The human side of geoscientists: comparing geoscientists' and non-geoscientists' cognitive and affective responses to geology

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Abstract

Geoscientists and non-geoscientists often struggle to communicate with each other. In this paper we aim to understand how geoscientists and non-geoscientists perceive geological concepts and processes, that is, how they think (cognitive responses) and feel (affective responses) about them . To this effect, using a mixed-methods approach, we compare mental models – people's representation of a phenomenon - of the subsurface, mining/quarrying, drilling, and flooding between geoscientists (n=24) and non-geoscientists (n=38). We identify four dominant themes which underlie their mental models: (1) degree of knowledge and familiarity, (2) beliefs about human interactions, (3) affective beliefs, and (4) beliefs about perceived impact of the processes. While the mental models of non-geoscientists focus more on the perceived negative environmental and economic impacts of geoscience, those of geoscientists focus more

on human interactions. We argue that mental models are the result of beliefs, including both cognitive and affective components, and that both need to be acknowledged for effective dialogue between the two groups to take place.

Introduction

Geoscience is an integral part of society, affecting local communities, citizens and scientists. In their work, geoscientists must engage and work with people from other backgrounds and disciplines (Barthel & Seidi, 2017), as their work often directly involves and impacts different publics (e.g. Juang *et al*., 2019). However, geoscientists often struggle to communicate with non-geoscientists, particularly around controversial topics such as resource extraction. For effective, dialogic communication (e.g. Davies and Horst, 2016; Wildson and Willis, 2004) between geoscientists and non-geoscientists to take place, both groups must understand one another, i.e., the audience they are engaging with (Pidgeon and Fischoff, 2011).

A starting point to understand each other is to investigate the differences in mental models between geoscientists (defined as anyone with at least a university degree in geology or geoscience) and non-geoscientists (those without such a degree). Specifically, we adopt the concept of mental models, which are defined as an individual's internal representation of a phenomenon, a way for people to interpret and navigate the world (Johnson-Laird, 1983, 2010, 2013; Libarkin *et al.,* 2003).

Libarkin *et al.* (2003) recognise four categories of cognitive (mental) models: "conceptual models" which are precise, highly-stable representations of the world used by geoscientists; "conceptual frameworks", organised and stable models of the world used by geoscientists; "naïve mental models", intuitive models of the world that so-called 'novices' fill with fragmented and unconnected knowledge; and "unstable mental models", unstable, incomplete and inexact mental models which are used by novices and easily modified. "Conceptual mental models" are the result of cognitive change, often due to repeated cognitive engagement with the same problems and phenomena, and thus we envisaged that geoscientists' mental models should conform to these, and non-geoscientists' mental models should conform to Libarkin's "naïve mental models" or "unstable mental models", as they are typically based on intuition and local knowledge.

Mental models have been previously used to understand geoscientists' and non-geoscientists' perceptions of climate change (e.g. Bostrom *et al.,* 1994), subsurface hydrology and geohazards (e.g. Gibson *et al.,* 2016), nuclear waste (e.g. Skarlatidou *et al.,* 2012) and sea-level change (e.g. Thomas *et al.,* 2015), with findings used to inform risk communication. Mental models have also previously been used to compare geoscientists' and non-geoscientists' perceptions (e.g. Gibson *et al.,* 2016). However, these mental models focus merely on cognitive components (e.g. Gibson *et al.,* 2016; Goel, 2007; Johnson-Laird, 2010, 2013; Shipton *et al.,* 2019) or on the cognitive superiority of geoscientists over non-geoscientists (Libarkin *et al.,* 2003; Vosniadou and Brewer, 1992). Here, we argue that mental models should also incorporate subjective and affective representations of a phenomenon, for both geoscientist and non-geoscientists.

Affect is a general positive or negative feeling that people may experience about an event, a situation, a technology or a process (Finucane *et al*., 2000). An affective response is thus the response to such an event, situation, technology or process, based on positive or negative feelings. Misperceptions of geological activities among the public are often attributed to affective and emotional processes (Devine-Wright, 2005; Finucane et al., 2000; Loewenstein et al., 2001). However, far less is known about the affective responses of geoscientists, and how they influence their mental models. The main contribution of this paper is to investigate how both cognitive and affective beliefs underlie the mental models of geoscientist and non-geoscientists.

To this end, we used a mixed-method approach and identified the cognitive (and affective underlying beliefs of geoscientists' and non-geoscientists' mental models. We argue that understanding differences and resemblances of both the cognitive and affective components of mental models of geoscientists and non-geoscientists is an important step in improving two-way communication between them about often-contested areas of the geosciences.

Materials and methods

The aim of this paper was to investigate the beliefs underlying the mental models of geoscientists vs non-geoscientists around geological concepts and processes and use this to build future communication strategies.

To that end, a face-to-face survey was conducted with geoscientists (n=24, recruited across Ireland) and non-geoscientists (n= 38, recruited in a rural community in Ireland) to compare their mental models and underlying beliefs about the subsurface of the Earth, applied-geoscience processes (mining/quarrying and drilling), and geohazards (flooding). To establish their mental models, respondents were asked to sketch the processes, geohazard, and the subsurface to any depth they wished. Follow up questions about respondents' emotions and perceived outcomes of the processes and hazard were also included in a short survey.

We used a mixed design of between-subjects (geoscientists vs non-geoscientists) and within-subjects design (sketches of subsurface, drilling, mining/quarrying, flooding). Moreover, a mixed methods approach was used (i.e., a mixture of qualitative and quantitative methods) to investigate these beliefs. Analysis of the qualitative results

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were done through qualitative thematic analysis and quantitative data were tested on statistical significance using IBM SPSS Statistics 24 software package.

Procedure

Face-to-face surveys were conducted among 38 non-geoscientist and 24 geoscientist participants as detailed below. A summary of the socio-demographics of both is presented in Table 1. Most geoscientists who took part in the study identified as male (58%), aged 21-29, and educated to degree level. The higher number of males is consistent with underrepresentation of females in geoscience (Dutt *et al.*, 2016). Most non-geoscientists identified as female (63%), aged 60 or older and educated to less than degree level.

Table 1. Sociodemographic details across all study participants.

	Geoscientists (n)	Non-geoscientists (n)
Female/ Male	42% females/ 58% males	63% females/37% males
Age		
16-21	0	1
21-29	14	7
30-39	3	7
40-49	1	8

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50-59	1	5
60 or older	0	13
Educational level		
less than degree level	0	18
to degree level	14	16
Other (higher than degree level)	4	2
Income		
≤ 20,000 euro	9	4
20,001-40,000	9	10
40,001-60,000	4	10
≥ 60,001	2	5
Household type		

Single-person (no children)	13	8
Two-person (no children)	4	17
Single-parent	0	0
Two-parent	3	9

Non-geoscientists were recruited on several locations in County Clare, western Ireland, between August 2017 and February 2018 (see Table 1 for socio-demographic details). County Clare was chosen because it is a popular destination for geoscientists from academia and industry in the Republic of Ireland (e.g. see Martinsen *et al.,* 2017). It is an excellent setting for non-geologists to learn about geology, as well as one of the top tourist destinations in Ireland. Given the popularity of the area with geologists, we also anticipated that non-geoscientists living in the area may have a relatively high level of familiarity with geology or with groups of geologists.

Invitation letters were posted to 50 addresses selected randomly using the online (Eir) phonebook and follow-up telephone calls were made to schedule a time for the survey to take place. This method was supplemented by convenience sampling in local businesses in Co. Clare. Details of those who did not wish to participate were immediately destroyed. Before commencing any interviews, following the university's ethical guidelines, all interviewees provided informed consent.

No incentives were offered for participation. The survey was administered in person by the lead author. Each survey took approximately 20-30 min to complete. Relevant spoken quotes by respondents during survey completion were written down by the lead author as support information and were included in the analysis.

Geoscientists were defined as people with a degree in geoscience, either working or doing research in the geosciences. They were recruited using convenience sampling techniques and ranged from MSc students (n=1), PhD students (n=11), postdoctoral researchers (n=7), to professional geoscientists working in geoscience industry and academia (n=4) or education centres (n=1).

All participants were offered the opportunity to have the results of the research sent to them by sharing their contact details. Contact details were immediately separated from the data to guarantee anonymity.

Face-to-face survey

The survey was aimed at assessing underlying beliefs of respondents' mental models of the subsurface, drilling, mining/quarrying, and flooding.

First, respondents were asked: 'please sketch the ground under your feet starting from the surface of the earth down to any depth'. They were then asked to make sketches of drilling, mining/quarrying and flooding, a common way of measuring mental models (e.g. Gibson et al., 2016).

For drilling, mining/quarrying, and flooding, there were follow up quantitative questions on the environmental and economic impacts, and the emotions associated with the processes and hazard. Flooding did not yield reliable scales for affective responses or significant results perceived impact, hence it was excluded from further analyses.

Perceived environmental and economic impact of the processes on a 5-point Likert scales ranging from totally disagree (1) to totally agree (5). To measure the perceived economic impact, after each sketch (of drilling, mining/quarrying and flooding) respondents were asked whether drilling or mining/quarrying *will improve the local economy*. Perceived environmental impact was measured by asking whether drilling or mining/quarrying *will have a negative impact on the local natural environment.*

Next, respondents were asked to rate how well a given emotion described their feelings towards drilling, mining/quarrying and flooding, respectively. They indicated, from a list of 16 different feelings on 5-point bipolar scales, of which 8 were negative emotions (i.e., irritated, angry, hostile, frightened, frustrated, upset, concerned, deceived) and 8 positive emotions (i.e., optimistic, satisfied, inspired, enthusiastic, relaxed, excited, safe and interested), which they identified with. The measures were based on scales previously used by Sjoberg (2007), Roderiquez *et al*., (2018), Visschers and Siegrist (2014). The positive and negative affective responses formed both reliable scales (see Table 2), and the mean scores on negative and positive affective responses were computed and used in further analysis.

Table 2. Reliability, Mean and Standard Deviations of scales of perceived impact and affective responses.

	Geoscientists			**Non-geoscientists**		
	Cronbach's Alpha	**M**	**SD**	**Cronbach's Alpha**	**M**	**SD**

Affective responses						
Negative affect drilling	0.881	1.49	0.61	0.918	2.32	1.02
Positive affect drilling	0.944	3.19	1.12	0.953	2.40	1.09
Negative affect mining/quarrying	0.853	1.42	0.53	0.886	2.28	0.97
Positive affect mining/quarrying	0.958	3.02	1.22	0.835	2.22	0.87
Perceived impact						
Economic impact drilling	N/A	3.40	1.27	N/A	2.62	1.08
Economic impact mining/quarrying	N/A	4.05	1.39	N/A	2.94	1.35
Environmental impact drilling	N/A	2.16	0.92	N/A	3.48	1.39
Environmental impact mining/quarrying	N/A	3.05	0.80	N/A	3.74	1.22

Note: Whenever Cronbach's Alpha was not relevant (i.e., for single items) N/A is written in the table.

Analysis strategy

Analysis of the sketches

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The sketches were analysed by means of thematic analysis to identify themes that were common to some or all of the sketches (Boyatzis, 1998; Marshall and Rossman, 1999). Thematic analyses were conducted manually by the first author.

Next, the first and second author pre-defined six indicators of knowledge and familiarity, namely: presence of *technical jargon*, *number of labels*, *number of layers*, *depth*, presence of appropriate *sense of scale* and presence of *human interactions* and activities in the sketch. They scored the sketches independently based on this. Pearson's correlation was used to determine the inter-rater reliability, which was deemed acceptable, (Pearson's $r \geq 0.7$, $p \leq 0.001$).

To test the differences between geoscientists and non-geoscientists on the six pre-defined indicators Independent Sample T-tests and ANOVA Repeated Measures analyses were conducted using IBM SPSS Statistics 24 software package.

Analyses of perceived impact and affective responses

As we had a mixed design of between-subjects (geoscientists vs non-geoscientists) and within-subjects (drilling and mining/quarrying), we conducted two ANOVA Repeated Measures with geoscientists and non-geoscientists as between-subjects variable and perceived impact and affective response as dependent variables, respectively. Posthoc t-tests as part of the ANOVA Repeated Measures were run to compare in detail the differences between geoscientists and non-geoscientists.

Results

Thematic analysis was used to analyse all sketches. We identified four common themes: (1) degree of knowledge and familiarity with the topics, (2) beliefs about human interactions, (3) affective beliefs, and (4) beliefs about the impact on the economy or environment.

Technical knowledge and familiarity

The mental models of geoscientists contained indicators of detailed, technical knowledge and familiarity with geoscience content stemming from years of training and from professional expertise (e.g., see Cronin *et al.,* 2004). Specifically, we identify five indicators of technical knowledge and familiarity.

These are the amount of *technical jargon*, which is defined as the presence of technical and subject-specific vocabulary in the labels of sketches; *sense of scale,* which refers to an indication of the awareness of the size of different elements included in the sketches (usually provided by a point of reference such as a scale bar); *number of layers,* the number of layers of rock or other material in the sketches; *number of labels,* the number of labels included in the sketches; and *depth,* which refers to the depth to which they sketched the subsurface, ranging from the ground surface (coded as 1) to the core (5).

ANOVA repeated measures tests revealed that, compared to non-geoscientists, across all four sketches geoscientists used more *technical jargon*, [F(1,42) = 6.776, p = 0.013], more *labels*, [F(1,54) = 8.294, p = 0.006], more *layers*, [F(1,54) = 9.083, p = 0.004], included a greater *sense of scale*, [F(1,54) = 4.229, p = 0.045], and extended their sketches down to a greater *depth* compared to non-geoscientists', [F(1,58) = 25.392, p ≤ 0.001], thereby indicating a higher level of knowledge and familiarity with geoscientific concepts and processes (Fig. 1a). This is consistent with the assumption that

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geoscientists have "conceptual mental models", which are developed based on their expertise and training in geoscience.

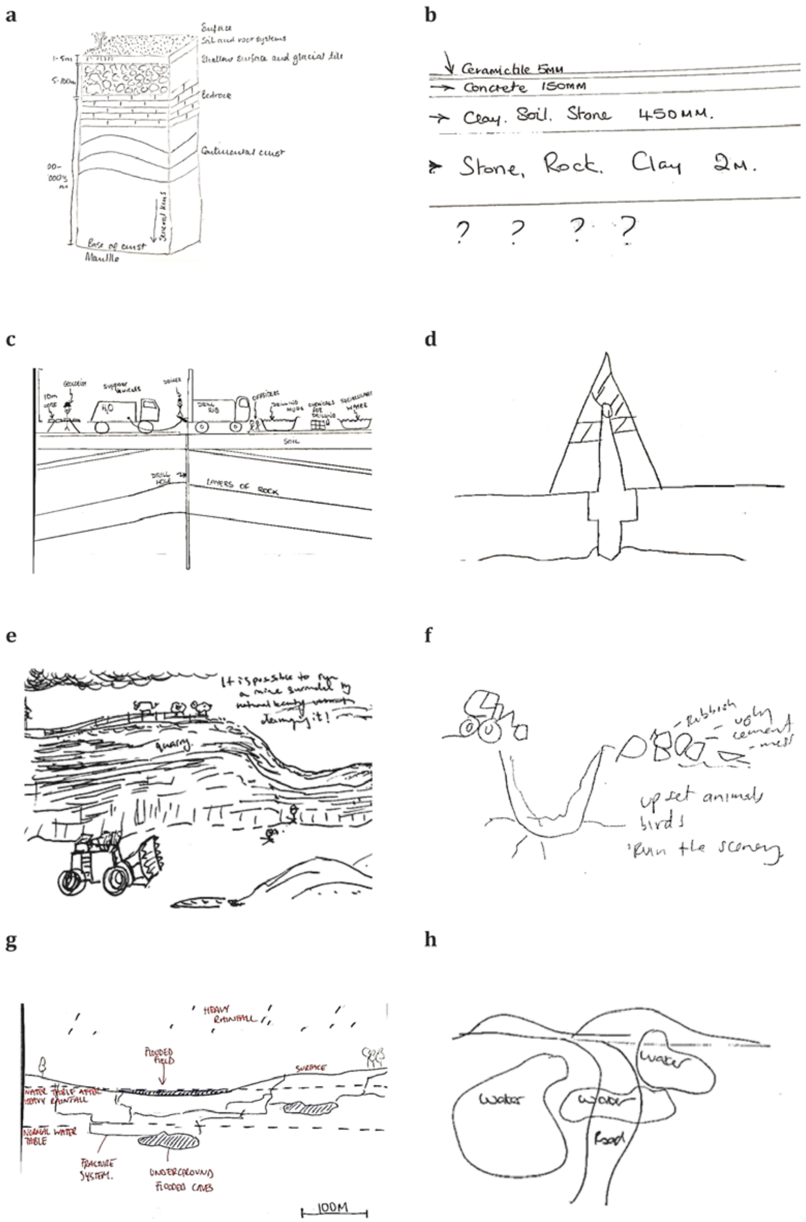
However, geoscientists' comments sometimes included knowledge that went beyond technical geoscience-related concepts, and incorporated elements of philosophy of science. For instance, one geoscientist labelled the different layers of the subsurface from a anthropocentric point of view as "*what we know*" (upper crust), "*what we think we know*" (lower crust), "*where we can make an educated guess*" (mantle), and "*anything goes*" (core). This indicates that geoscientists do not limit themselves to technical knowledge, but also tap into other types of knowledge in constructing their mental models.

Furthermore, non-geoscientists' sketches showed evidence of local knowledge about their own area (Fig. 1b), which constitutes lay expertise (e.g. Cronin *et al.,* 2004). Such lay knowledge co-occurred with indications of low levels of familiarity and technical knowledge relating to geological concepts and processes.

For instance, when asked to sketch the ground under their feet, one non-geoscientist included thickness of layers at millimetre scale and labelled the layers using specific terms such as "*ceramictite*" and "*concrete*" - indicating local knowledge - but did not know what was below the layer labelled "*stone, rock, clay 2m*", as is evinced from the "*? ? ? ?*" label (Fig. 1b), denoting uncertainty or unfamiliarity. This sense of unfamiliarity with the subsurface and geological timescales was also noted by Stewart (2016). Uncertainty was similarly expressed through written notes accompanying the sketches such as "*not sure*", "*Cannot envisage this enough to draw. Sorry.*" or "*no idea how far down that goes*".

Hence, even though the mental models of non-geoscientists contain few indicators of technical knowledge and familiarity, they possess lay knowledge, which is valuable for geoscientists and is for example recognised in citizens science projects that includes the non-geoscientists in research projects (e.g., Nature, 2018; Skarlatidou *et al.,* 2012; Vera, 2018).

Therefore, while at first glance it appears that geoscientists possess conceptual mental models and non-geoscientists possess naïve mental models, given that geoscientists have more familiarity and technical knowledge related to geoscience, we find that underlying this, the mental models of geoscientists and non-geoscientists are complex and reflect different beliefs in both groups.



255

256 Fig. 1. Comparison of sketches made by geoscientists (left column) and non-geoscientists (right
257 column). The sketches are of: **a**,**b**, the subsurface; **c**,**d** drilling; **e**,**f**, mining/quarrying; **g**,**h**,
258 flooding.

Beliefs about human interactions

A second theme that emerged from the sketches was the number of human interactions, defined as the presence of humans or human-operated machines in the sketches, comments or labels, including human-built structures such as a field, road or house. A group of humans close together in the sketch was counted as one human interaction.

An ANOVA repeated measures revealed a significant main effect of human interaction across the sketches of drilling, mining/quarrying and flooding, (Wilks' $\lambda = 0.51$); [F(2, 53) = 25.02, $p \leq 0.001$], and showed more human interactions in the sketches of geological processes (drilling and mining/quarrying) compared to geohazards (flooding), ($p \leq 0.001$). Interestingly, geoscientists included more human interactions than non-geoscientists in all sketches, [(F(1,54) = 24.610, $p \leq 0.001$]. Thus, mining/quarrying activities were sketched from a very human lens by geoscientists, who highlighted details of people working in a lab or processing plant, or people using instruments such as microscopes (Fig 1c). Geoscientists also included details of labour division, showing people with tools performing different functions, or stick figures with hammers or helmets doing different types of work (Fig. 1c,e).

Non-geoscientists included fewer human interactions in their sketches, but contributed to the human interaction theme in their written comments in a different way. For instance, one non-geoscientist wrote: *"People are not interested in geology*". These results contrast with earlier reports of an anthropocentric view of the subsurface on the part of non-geoscientists, with geoscientists focusing on technical geoscience concepts rather than on human elements (e.g., Gibson *et al.,* 2016). A possible explanation is that mining/quarrying and drilling are tied to geoscientists' jobs and therefore including humans in the sketches may be geoscientists' way of highlighting the social process of science and their work, perhaps in opposition to the focus on scientific findings, facts and 'breakthroughs' often seen in media coverage of science (Nelkin, 1995).

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Affective beliefs

Drilling and mining/quarrying are highly controversial geological processes, and therefore we asked geoscientists and non-geoscientists to indicate their affective responses to them (see method), which refers to a general positive to negative feeling about these geological processes (Visschers and Siegrist, 2008). An ANOVA repeated measures analysis revealed a significant interaction effect, (Wilks' $\lambda = 0.76$); [F(3,57)= 5.977, $p \leq 0.001$], indicating that geoscientists and non-geoscientists have different affective responses to drilling and mining/quarrying.

As illustrated in Fig. 2, the posthoc tests effect revealed that non-geoscientists had more negative affective responses to mining/quarrying, [t(59) = -3.96, $p \leq 0.001$], and drilling, [t(60) = -3.69, $p \leq 0.001$], compared to geoscientists. Instead, geoscientists have more positive affective responses to mining/quarrying [t(59) = 2.94, p = 0.004], and drilling, [t (60) =2.85, p = 0.005], compared to non-geoscientists. Geoscientists have far more positive than negative affective responses to both drilling and mining/quarrying, whereas non-geoscientists' strength of positive and negative affective responses did not statistically differ.

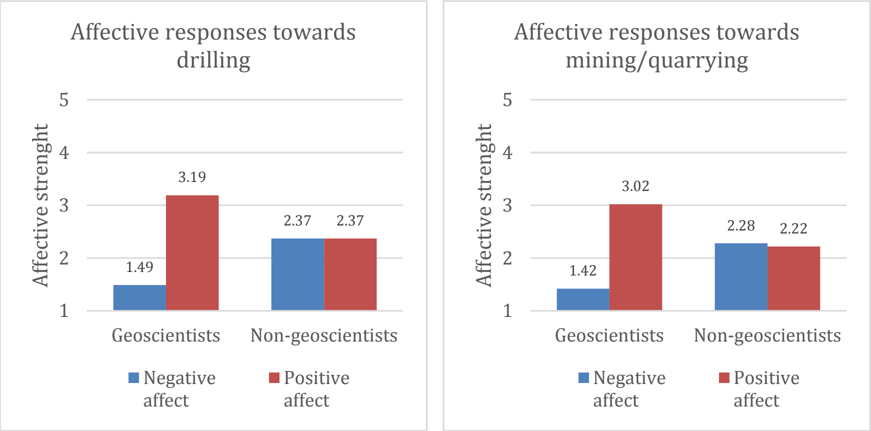

Fig. 2. a,b Affective responses towards drilling and mining/quarrying. Mean values of positive and negative affect responses are compared between geoscientists and non-geoscientists for different processes, namely (a) drilling and (b) mining/quarrying; measurements are on a scale from 1 (weak affective strength) to 5 (strong affective strength).

Recent research (Perlaviciute *et al.,* 2017) indicates that negative responses from members of the general public are often overrepresented in the media. This, combined with our result that geoscientists have fewer negative affective and more positive affective responses to geological processes like drilling and mining/quarrying than non-geoscientists, explains why geoscientists may misperceive affective responses of non-geoscientists.

Beliefs about environmental and economic impact

An environmental or economic impact theme emerged from thematic analysis of the sketches. Non-geoscientists' sketches often highlighted environmental effects of drilling and mining/quarrying processes (e.g., noise from drilling, environmental degradation or pollution) through labels (Fig 1h), indicating that negative environmental impacts were at the forefront of their mind. For instance, this was illustrated by labels such as *"Grassy* *bank 3-4m high to screen activity from the outside world as process is unsightly”*. The theme was also present in written comments by non-geoscientists, such as: *“I live on the River Shannon where we have a large colony of dolphins. Several years ago a company wanted to open a quarry that requires blasting up to 3-6 times a week. Locals objected to this blasting as we believed that the blasting would affect the dolphins by way of seismic waves travelling through the ground and out to the Shannon. WE WON!”* In general, it was clear that non-geoscientists tended to relate their negative emotions with the negative impact of geoscience on the environment, such as in the label “*ruin the scenery, upset animals, birds*” (Fig. 1h).

Through their labels, non-geoscientists also reported concern about the negative effects of geoscience on the economy (e.g., loss of tourism), as for example evinced by the label “*Road networks e.g. quarries, need to be in the Shannon [area] – this is a tourist area, not here”*. One label by a non-geoscientist is taken to imply a lack of trust in how geoscience operates: *“I think it is unfortunate that most geological studies are funded by large industry*”.

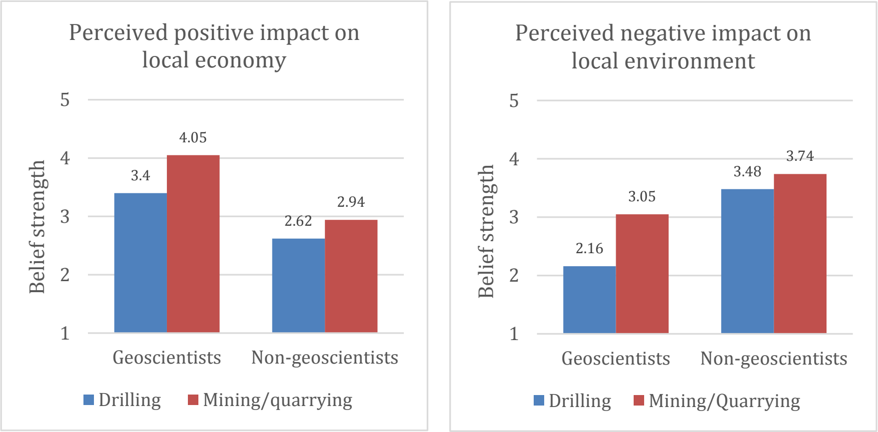

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Fig. 3. Perceived economic and environmental impact. (a) Mean scores in answer to beliefs on the extent to which they agreed that drilling and mining/quarrying would improve the local economy; (b) Mean scores in answer to beliefs on the extent to which they agreed that drilling and mining/quarrying would have a negative impact on the local natural environment; measurements are on a scale from 1 (totally disagree) to 5 (totally agree).

These conclusions were confirmed in additional survey questions about the effects of drilling and mining/quarrying on the local economy and environment (see method). An ANOVA repeated measures analysis showed a significant interaction effect: geoscientists and non-geoscientists differed in their beliefs about impact across the geological processes of drilling and mining/quarrying, (Wilks' $\lambda = 0.773$); [F(3, 57) = 5.578, p = 0.002]. Specifically, non-geoscientists perceived greater negative impacts on the local environment for drilling, [t(49) = -3.59, p = 0.02], and mining/quarrying, [t(51) = -2.15, p = 0.036], compared to geoscientists. In contrast, geoscientists perceived greater positive impacts on the local economy from drilling, [t(55) = 2.43, p = 0.019], and mining/quarrying, [t(56) = 2.92, p = 0.005], compared to non-geoscientists (Fig. 3).

Although geoscientists indicated an awareness of the negative effects of geoscience on the environment in written comments on the survey, they generally downplayed the negative effects and were sometimes defensive in tone. For example, one geoscientist while answering that mining/quarrying would, in his opinion, lead to an increase in numbers of visitors and tourists to the area, wrote: "*Giving you an example, in North Yorkshire* [UK]*, there is a salt mine near Staithes where tourists are attracted by its geology and natural beauty. The mine is not necessarily degrading the importance of the land as a long as [there is] a good system keeping it in place.*" Another label written by a geoscientist illustrates a defensive tone: "*It is possible to run a mine surrounded by natural beauty without damaging it!*" (Fig. 1g).

In conclusion, beliefs about the environmental or economic impact underlie the mental models of both geoscientists and non-geoscientists, which suggests that they both are concerned about how geoscience processes impact the environment and economy. However, while geoscientists tend to highlight the positive impacts, often in a defensive tone, non-geoscientists tend to dwell on the negative ones.

Discussion

We have highlighted the differences in mental models between geoscientists and non-geoscientists and their underlying beliefs when considering geoscience processes, hazards and concepts. We found support for our assumption that, for both geoscientists and non-geoscientists, mental models include cognitive (based on rational thoughts) and affective (based on feelings and emotions) components, and are therefore not consistent with the existence of rigidly defined categories of mental models which focus merely on cognitive components (e.g. Gibson *et al.,* 2016; Goel, 2007; Johnson-Laird, 2010, 2013) or on the cognitive superiority of geoscientists over non-geoscientists (Libarkin *et al.,* 2003; Vosniadou and Brewer, 1992). Hence, we argue that mental models should be redefined as *the cognitive and affective representation of a phenomenon*.

The presence of strong positive affective responses and human interaction in the mental models of geoscientists contrasts with the myth of the scientist (Barthes, 1974) as an impartial, detached observer of reality, and dissents with the rhetoric of fact-based knowledge (Mitroff, 1974). In other words, geoscientists are first and foremost human. The results contribute to the erosion of the ideal of the objective scientist, focused solely on facts, helping to deconstruct the myth of science that sees scientists as impartial and detached.

Understanding differences and resemblances of both the cognitive and affective components of mental models of geoscientists and non-geoscientists is an important step in improving the communication between them, for instance when discussing often-contested areas of the geosciences such as resource extraction (see Stewart and Lewis, 2017). As a practical step, in communicating with each other, geoscientists and non-geoscientists will need to acknowledge their differences and focus on commonalities in order to find common ground. For instance, geoscientists may be able to reach wider audiences by acknowledging the affective components of their mental models and their concern for perceived negative impacts of geoscience on the economy and environment, and including feelings and affect in their chosen form of communication (e.g., personal motivations for their research). Such forms may include storytelling and narrative, which typically include both affective and cognitive components, and ought to be the most successful mode of communication of geoscience between the two groups, a finding consistent with previous recommendations for science communication (Dahlstrom, 2015). Geoscientists may also wish to acknowledge and tap into local knowledge held by non-geoscientists, for example simply by asking non-geoscientists questions about their local area. At the same time, by recognising that geoscientists' mental models are based on emotions too, non-geoscientists may be better able to engage with them. Overall, showcasing geoscience as a human activity ought to help improve dialogue between the two groups.

Concluding remarks: the human side of geoscientists

Our finding that geoscientists are, first and foremost, human, is a key realisation for geoscience communication practitioners. Putting the human element at the centre of communication strategies will help achieve meaningful dialogue between geoscientists and non-geoscientists.

Geoscientists, specifically those who conduct research on resources, energy, earth and environmental science, are increasingly required to wear multiple hats in engaging with non-geoscientists in order to tackle societal challenges around energy and resources. Therefore, an increased mutual understanding of the thoughts and feelings of geoscientists and non-geoscientists will help facilitate dialogue between the two groups.

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Supporting information

1 Images of sketches

Data availability

All data underlying the results is available in the manuscript and supporting information. Additional data around this project is available from the corresponding author.

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Competing interests.

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Author contributions.

All authors conceived and planned the study; A.L. conducted the data collection; A.L. and G.S. analysed and interpreted the data; all authors helped to draft the manuscript.