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 activities, 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, and drilling, between geoscientists (n=24) and non-geoscientists (n=38) recruited in Ireland. We identify four dominant themes which underlie their mental models: (1) degree of knowledge and familiarity, (2) presence of humans, (3) affective beliefs, and (4) beliefs about perceived impact of the activities. While the mental models of the non-geoscientists focused more on the perceived negative environmental and economic impacts of geoscience, as well as providing evidence of lay

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

Introduction

Geoscience activities such as mining, quarrying, hazard risk management and landscape management are 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 and risk communication. For instance, past studies have investigated public perception and risk communication in the case of fracking (e.g. Boudet *et al.*, 2014; Thomas *et al.*, 2017), carbon capture and storage (Seigo *et al.*, 2014) and earthquakes (e.g. Marincioni *et al.*, 2012). Specifically, in the context of earthquake risk communication, Marincioni *et al.* (2012) studied the case of the 2009 earthquake in l'Aquila, Italy, as a result of which 308 people died: the authors identified a lack of clear communication from the risk management authorities to the public in relation to earthquake prediction and structural resistance of buildings. In the context of public perception of carbon capture and storage, Seigo *et al.* (2014) compared risk and benefit perceptions of the technology in different Canadian regions, and found that predictors of risk perceptions, such as sustainability concerns, did not vary across different regions and were unrelated to familiarity with the technology. The authors also point out that there is a need to address lay people's "misconceptions" related to carbon capture and

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storage, in order for informed decisions to take place. In the context of a public perceptions of fracking, Thomas *et al.*, 2017, in a literature review, identified mixed levels of awareness of shale operations, as well as ethical issues and widespread distrust of responsible parties. Other studies concerning fracking, such as that by Boudet *et al.* (2014), which looked at public perceptions of fracking in the U.S., found differences in perception between different genders, socioeconomic backgrounds, income levels and level of education, and highlighted a need for "wide ranging and inclusive public dialogue" around the risks and benefits of fracking. 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 from which to understand each other is to investigate the differences 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 investigate those differences by adopting the concept of mental models, which are defined for our purposes as an individual's internal representation of a phenomenon, or a way for people to interpret and navigate the world (Johnson-Laird, 1983, 2010, 2013; Libarkin *et al.,* 2003).

In the context of science education, 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 (for instance, aquifer models); "conceptual frameworks", organised and stable models of the world used by geoscientists (for instance, the notion of gravity); "naïve mental models", intuitive models of the world that so-called 'novices' fill with fragmented and unconnected knowledge (for instance, the notion that the Earth is flat); and "unstable mental models", unstable, incomplete and inexact mental models which are used by novices and easily

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modified (for instance, the idea that the Earth is spherical, but with flattened portions where humans live). "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 previously been used to understand non-experts' perceptions of geoscience-related topics. For instance, Bostrom *et al.* (1994) investigated non-experts' mental models of climate change, and found that global warming was regarded as "both bad and highly likely". Zaunbrecher *et al.*, (2018), investigating non-experts' mental models of geothermal energy, identified varying attitudes and knowledge levels among participants, with negative emotions being evoked by the concepts of drilling and power stations. These studies also stress that there are emotional or affective components underlying the mental models of non-experts.

However, most mental models studies 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;

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Finucane et al., 2000; Loewenstein et al., 2001). The role of emotions in risk perception and communication around nuclear waste has been investigated by Sjöberg (2007), who argued that emotions such as interest play an important role in risk perception and attitude. In Zaunbrecher *et al.'s* (2018) study of public perception of geothermal energy, an association between positive emotions and the acceptance of geothermal energy was identified. Similarly, Thomas *et al.* (2015) identified negative emotions in the mental models of non-experts when considering sea level change. While these studies recognise emotions as a component of the mental models of non-geoscientists, far less is known about the affective responses of geoscientists, and how they influence their mental models, as well as how they compare with those of non-geoscientists.

Compared with the number of studies focusing on non-experts or publics, fewer studies have used mental models to compare experts' and non-experts' perceptions. For example, Gibson *et al.* (2016) identified mismatches in perceptions of subsurface hydrology and geohazards between experts and non-experts. In a study comparing experts' and non-experts' mental models of nuclear waste, Skarlatidou *et al.* (2012) described non-experts' negative perceptions of nuclear waste as co-existing with a positive attitude towards nuclear energy, as well as lack of knowledge and familiarity, and discussed implications for risk communication. In the context of sea-level change, Thomas *et al.* (2015) identified both consistencies between the mental models of experts and non-experts, and barriers to publics engaging with the issue, and argued that factors other than knowledge bear an influence on the mental models of non-experts. These factors include "levels of concern, perceptions of self-efficacy and responsibility, trust and ways of actively engaging with or avoiding the issue" (Thomas *et al.*, 2015, p.78).

The main goal of the present paper is to investigate how both cognitive and affective beliefs underlie the mental models of geoscientist and non-geoscientists.

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To this end, we used a mixed-method approach and identified the cognitive and affective underlying beliefs of geoscientists' and non-geoscientists' mental models. While our sample of geoscientists (n=24) working across Ireland and non-geoscientists (n=38) recruited in a rural community in Ireland is not representative of all geoscientists and non-geoscientists in all settings, we suggest that understanding differences and resemblances of both the cognitive and affective components of mental models of geoscientists and non-geoscientists can help to improve two-way communication between them about often-contested areas of the geosciences.

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Materials and methods

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

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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 activities (mining/quarrying and drilling), and geohazards (flooding). To establish their mental models, respondents were asked to sketch the activities, geohazard, and the subsurface to any depth they wished. Follow up questions about respondents' emotions and perceived outcomes of the activities and hazard were also included in a short survey.

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In our analyses, we used a mixed experimental set-up of between-subjects design (to compare geoscientists vs non-geoscientists) and within-subjects design (to investigate sketches of subsurface, drilling, mining/quarrying, flooding within our sample group of geoscientists or non-geoscientists). Moreover, a mixed methods approach was used (i.e.,

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a mixture of qualitative and quantitative methods) to investigate their beliefs about the subsurface and geological activities. Analyses of the qualitative results were done through qualitative thematic analysis (Boyatzis, 1998; Marshall and Rossman, 1999) and quantitative data were tested on statistical significance using the IBM SPSS Statistics 24 software package.

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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. The geoscientists who took part in the study ranged in age from 21 to 59, with most identifying 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, and their age ranged from 16 to 60 or over. For a discussion of the limitations associated with our sample, see Limitations.

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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
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

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 University College Dublin'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), and 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 qualitatively assessing underlying beliefs of respondents' mental models of the subsurface, drilling, mining/quarrying, and flooding. This qualitative analysis was supplemented by quantitative analysis of survey responses.

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

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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 activities and hazard. Flooding did not yield reliable scales for affective responses or significant results for perceived impact, hence it was excluded from further analyses and from the rest of the results.

Perceived environmental and economic impact of the activities were measured 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 and mining/quarrying) 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 and mining/quarrying, respectively. They indicated which feeling they identified with 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). The measures were based on scales previously used by Sjöberg (2007), Roderiquez *et al*., (2018), and Visschers and Siegrist (2014). The negative and positive affective responses both formed reliable scales (Table 2), which is indicated by scores of Cronbach's Alpha of 0.70 or higher (Peterson, 1994), and the mean scores on negative and positive affective responses were computed and used in further analysis.

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Table 2. Reliability, mean (M) and standard Deviations (SD) of scales of affective responses and perceived impact.

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	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

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 authors pre-defined six indicators of knowledge and familiarity, namely: amount of *technical jargon*, 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; *depth*, which refers to the depth to which they sketched the subsurface, ranging from the ground surface (coded as 1) to the core (5);

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and *human interactions*. The authors 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 the IBM SPSS Statistics 24 software package.

These results informed our qualitative analysis of the sketches.

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 variables 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 cognitive and affective responses of geoscientists and non-geoscientists.

Results

Thematic analysis was used to analyse all sketches and written comments on the survey. We identified four common themes: (1) knowledge and expertise relative to the topics, (2) beliefs about human interactions (presence of humans in the sketches), (3) affective beliefs, and (4) beliefs about the impact on the economy or environment.

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Knowledge and expertise

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, the sketches made by geoscientists extended down to a greater *depth*, included more *technical jargon* related to geoscience, more *labels*, more *layers* within the Earth's interior, and a greater *sense of scale*, compared to those of non-geoscientists (Fig. 1). For instance, it was common for geoscientists to extend their sketches down to the mantle and/or core.

It is not surprising that geoscientists included these indicators of technical knowledge in their sketches given that drawing and sketching the landscape and the Earth's interior are skills typically acquired during geoscience undergraduate education (Johnson & Reynolds, 2006) and given the importance of spatial visualisation as a geoscience skill (Titus & Horsman, 2009). Without being prompted to do so, some geoscientists also included colours and colour-coding in their sketches, which is another habit likely to have been acquired during undergraduate geoscience training and thus linked to technical knowledge. Geoscientists may also have enjoyed the task of sketching to a greater extent, wanting to provide as much information as possible: for instance, a sense of enjoyment was reflected in the inclusion of smiles on the faces of stick figures in one geoscientist's sketch, which also included different types of fossils and crystal shapes (Fig. 1g). It was not uncommon for geoscientists to include exclamation marks in their labels, such as "*Hawaii!*", indicating engagement with the process of sketching and enjoyment. A greater degree of technical knowledge and familiarity with geoscience in the sketches of geoscientists is consistent with the assumption that geoscientists have "conceptual mental models", which are developed based on their expertise and training in geoscience.

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Deleted: *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

Deleted: *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 ...

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Conversely, the lower levels of detail and technical knowledge in the sketches of non-geoscientists may reflect lack of knowledge but may also be linked to a lack of interest in the topics or a perception of science as inaccessible and exclusive. The notion that science can be viewed as a distant and inaccessible entity by non-scientists was identified in previous studies of public perception of risks (Bickerstaff *et al.*, 2006; Michael, 1992).

Furthermore, geoscientists' comments and sketches 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 an 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. Religious belief systems also surfaced among participants, with one non-geoscientist stating: "[…] *we disagree on that [that ammonoid fossils are much older than humans]. I believe in the genesis and that humans arrived at the same time as animals.*" In this case, these beliefs were deemed by the participant to be in opposition to the science and specifically to the geoscience concept of geological time which the survey brought to the fore.

Lay expertise

The non-geoscientists' sketches contained indicators of local knowledge about their own area (Fig. 1b), which we interpret as lay expertise (e.g., Cronin *et al.* 2004; Wynne, 1996). Lay expertise is here taken as a form of knowledge that is relevant to and can contribute to the scientific discourse (see Collins and Evans, 2002). For example, one non-geoscientist's sketch (Fig. 1h) of mining/quarrying included historical details, such

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as the historical ownership of mines by "*Judge Comyn*" and the "*government*", as well as the location of historical phosphate mines and the past site of "*surface mining and blasting*". Another non-geoscientist noted the presence of a "*water reservoir on top of Black Head*" in a comment written on the sketch, while also adding at the end of the survey: "*Having lived in Meath for 20 years, I was aware of mining in Tara Mines and the creation of Newgrange Visitor Centre.*" In addition, a non-geoscientist included the subsurface depth beneath which water could be found in their local area, alongside the label: "*Drilling for water around Kilkee area. Good supply found*".

Such lay knowledge co-occurred with indications of low levels of familiarity and technical knowledge relating to geological concepts and activities. 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), indicating uncertainty or unfamiliarity. 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*".

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Concluding remarks

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In conclusion, 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 citizen science projects that include the non-geoscientists in research projects (e.g., Nature, 2018; Skarlatidou *et al.*, 2012; Vera, 2018).

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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 both geoscientists and non-geoscientists are complex and reflect different knowledge in both groups.

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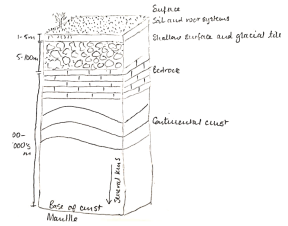

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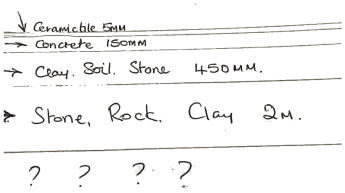

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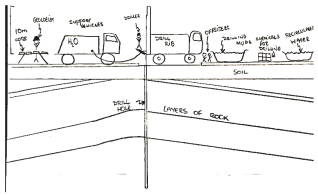

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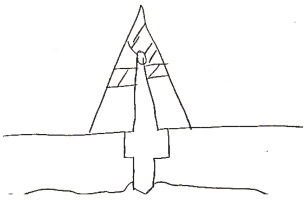

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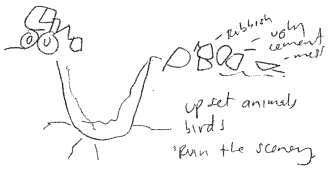

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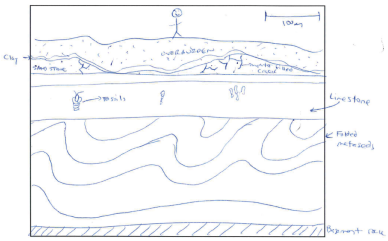

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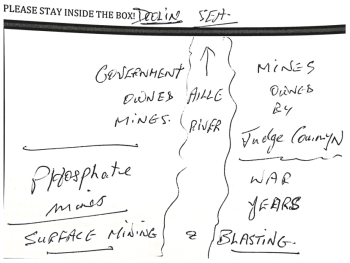

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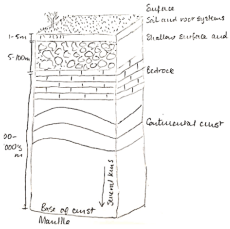

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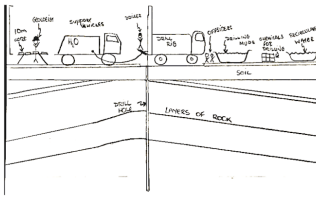

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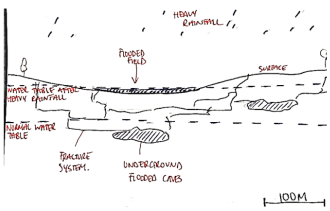

Fig. 1. Comparison of sketches made by geoscientists (left column) and non-geoscientists (right column). The sketches are of: **a,b**, the subsurface; **c,d** drilling; **e,f**, mining/quarrying; and **g,h,** subsurface (left), and mining/quarrying (right).

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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. Geoscientists' sketches typically included human interactions. In particular, 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).

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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

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.

Deleted: , perhaps in opposition to the focus on scientific findings, facts and 'breakthroughs' often seen in media coverage of science (Nelkin, 1995).

These findings on human interactions are confirmed by Independent Sample T-tests, which indicate that geoscientists included more human interactions than non-geoscientists when sketching drilling, [$t(56) = 3.77$, $p \leq 0.001$] and mining/quarrying,

[t(56) = 3.14, p = 0.003] . It is worth noting that, for the purposes of this analysis, a group of humans close together in the sketch was counted as one human interaction.

Affective beliefs

Drilling and mining/quarrying are highly controversial geological activities, 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 activities (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 had 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 had 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.

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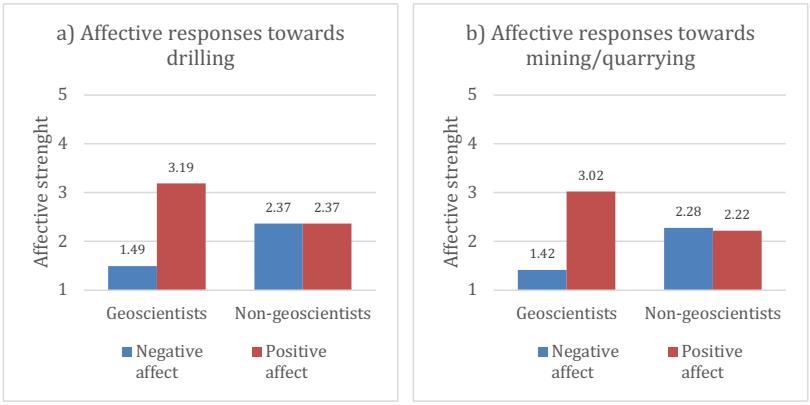

Fig. 2. a,b Affective responses towards drilling and mining/quarrying. Mean values of positive and negative affect responses are compared between geoscientists and non-geoscientists for different activities, namely (a) drilling and (b) mining/quarrying; measurements are on a scale from 1 (weak affective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

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It should be pointed out that many of the geoscientists in our sample worked in research in geoscience activities (though area of research was not formally gathered), which could have resulted in more positive affective associations with their field of research, such as feelings of safety (cf. Mearns and Flin, 1995).

Deleted: 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 activities (e.g., noise from drilling, environmental degradation or

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pollution) through labels (Fig 1f), 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!"* Another non-geoscientist, when sketching rock drilling, wrote "*causing underground problems, release of gas, etc., poisoning wells etc."* In general, it was clear that the non-geoscientists tended to associate negative emotions with the negative impact of geoscience on the environment, such as in the label "*ruin the scenery, upset animals, birds*" (Fig. 1f).

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*". Lack of trust in industry and government has previously been identified as a dominant theme in a review of public perceptions of hydraulic fracturing for shale gas and oil (Thomas *et al.*, 2017).

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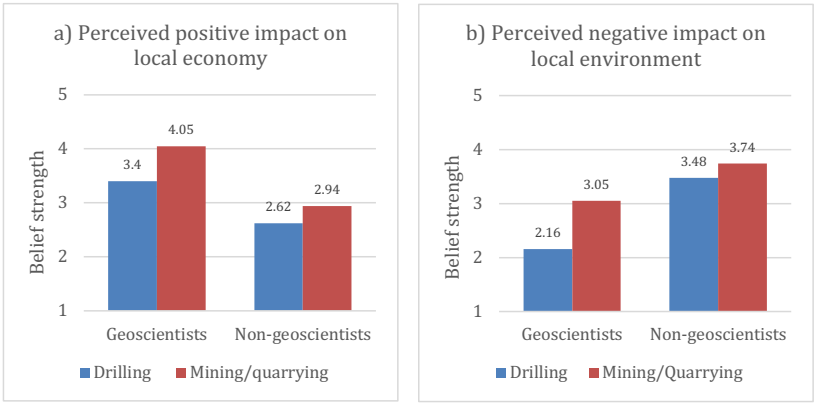

Fig. 3. Perceived economic and environmental impact. (a) Mean scores in answer to beliefs on the extent to which they agreed that drilling and mining/quarrying would improve the local economy; (b) Mean scores in answer to beliefs on the extent to which they agreed that drilling and mining/quarrying would 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 activities 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).

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In line with previous studies of perceptions of the underground (Partridge *et al*., 2019), we recognised tensions between economic values and environmental values in comments written on the survey, such as "*Drilling for a well for water is ok. Drilling for oil or gas is not necessary. Invest in solar and wind energy alternatives. Fracking is just idiotic.*" Such comments tended to equate fracking with a threat, associated with fear. Another participant wrote: "*Concerned about fracking if not properly supervised*". This tension may be linked to a desire for control (cf. Hooks *et al*. 2019) and regulation of geoscience activities and technologies (e.g., GSI, 2016), as typified by comments such as "*Concerned about fracking if not properly supervised*" or "*Groundwater pollution with farming practices, I would like it to be more controlled.*"

Geoscientists, while indicating an awareness of the negative effects of geoscience on the environment in written comments on the survey, generally downplayed the negative effects and were sometimes defensive in tone. For example, one geoscientist while answering that mining/quarrying would 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 activities impact the environment and economy. However, while geoscientists tended to highlight the positive impacts, often in a defensive tone, non-geoscientists tended to dwell on the negative ones.

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Discussion

We have highlighted the differences in mental models between a sample of Irish geoscientists and non-geoscientists and their underlying beliefs when considering geoscience activities 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). Indeed, we find that the mental models of both groups are complex reflections of different knowledge, beliefs and affect. 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 (Mitroff, 1974), and dissents with the rhetoric of fact-based knowledge. 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. Whilst the notion that all experts are affected by biases when making judgements under uncertainty has been known by scholars at least since the work of Tversky & Kahneman (1974), this is not commonly recognised within the geoscientific community (e.g., see Curtis, 2012). We have shown that geoscientists and non-geoscientists alike go beyond facts into emotional territory when constructing their mental models.

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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 may wish to acknowledge their differences and focus on commonalities in order to find common ground. For instance, given that both geoscientists and non-geoscientists are concerned with the impacts of geoscience on the economy and the environment and given that both groups incorporate affect in their mental models of geoscience concepts and activities, geoscientists may be able to reach wider audiences by acknowledging these concerns and affective components, and including feelings and affect in their chosen form of communication (e.g., personal motivations for their research). In addition, geoscientists may benefit from using storytelling and narrative, which typically include both affective and cognitive components, as their chosen modes of communication, a recommendation consistent with previous science communication research (Dahlstrom, 2015). If geoscientists acknowledge the emotional component of their mental models, this may also lead them to reflect on the meaning of scientific knowledge and to change their view of themselves as keepers of knowledge. On one hand, this could influence how they communicate their work and activities to geoscientists and non-geoscientists, but it could also lead to a broader understanding of epistemology and the social component of geoscience on the part of geoscientists (see Stewart, 2016).

Given that non-geoscientists often incorporate lay expertise in their mental models, in order to build trust and common ground, 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

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711 better able to engage with them. Overall, showcasing geoscience as a human activity
712 ought to help improve dialogue between the two groups.

713 *Limitations*

714 While this mixed-method study highlights differences and similarities between the
715 mental models of geoscientists and non-geoscientists, it should be noted that the sample
716 size is small, and thus our results need to be interpreted with care. Future research is
717 needed to validate our conclusions. It should further be noted that the geoscientists who
718 took part in this study were primarily highly-educated males working in applied
719 geoscience research at the time the survey took place (only 2 worked outside of
720 research), and they were younger compared to the non-geoscientists who took part (for
721 details, see Materials and Methods). The latter is fairly representative for geoscientists
722 (e.g., Dutt *et al.*, 2016), however, we cannot say with certainty that these differences in
723 socio-demographics play a role in the differences we find. For example, female and
724 younger geoscientists may hold different perceptions of geoscience activities and their
725 impacts (cf. Seigo *et al.*, 2014). However, this does not influence our main conclusion
726 that geoscientists' mental models are influenced by both cognitive and affective
727 responses.

728

729 # Concluding remarks: the human side of

730 # geoscientists

731 Our finding that geoscientists stray beyond facts into the realm of emotions and beliefs
732 in constructing their mental models of geoscience concepts and activities is a key
733 realisation for geoscience communication practitioners. We have argued that putting the

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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.

Acknowledgements.

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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.

The authors declare no competing financial interests.

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.

Reply to Editor

Dear Editor,

Thank you very much for your helpful and thorough review of our manuscript. We have replied to your comments below (with editorial comments in bold and our comments below each one; please note, in our replies we include line numbers referring to the annotated manuscript version above) and have made changes to the manuscript. These changes can be seen both in the annotated version and in a clean copy. Please note that both these manuscripts also incorporate the previous changes we have made after peer review, as well as these latest changes ones after editorial review. We look forward to your feedback and thank you again for your consideration of our work.

Best wishes,

Anthea Lacchia on behalf of all co-authors

Response to Editorial Comments

General comment:

I caution the authors against drawing conclusions beyond the scope of this study. For example, I wonder if the outcomes would be different with, for example, a non-geoscientist population that benefits from oil and gas extraction, or a geoscientist population that is focused more on basic research and less on industry.

We take the editor's point and do not wish to suggest that our conclusions are valid for all geoscientists or non-geoscientists. We have addressed this by mentioning the make-up of our sample at several points throughout the manuscript (for instance, see lines 18, 160-167, 170-171, 713-727) and making clear the limitations of this study (we have added a section entitled *Limitations* in the discussion at lines 713-727 in annotated manuscript above). Please see comments below for further details in response to this.

Specific comments (Page/Line):

12 Evidence for this statement, and does this communication struggle go both ways as stated?

We have now provided evidence in the form of examples of studies reporting communication issues between geoscientists and non-geoscientists in the introduction (lines 41-64). As such, we suggest leaving this sentence in the abstract as it is (i.e., line 12 of annotated manuscript: 'Geoscientists and non-geoscientists often struggle to communicate with each other.') as a means of introducing the broad topic of the paper.

15 delete space before .

This has been done.

18 after (n=38), say where your sample set is from, as it is pretty specific

We have done this now by adding 'recruited in Ireland' in line 18.

21 Should be edited from "mental models of non-geoscientists focus more on" to "mental models of the non-geoscientists focused more on," as you cannot generalize your findings out to all geoscientists.

Thank you for pointing this out. We agree and have made this change (lines 21 and 29).

22 see comment above for (1/21) and change to "the geoscientists focused"

This has been done.

23 this human interactions interpretation seems thin to me. Human interactions with… the environment? Or do you mean the role of humans incl. geoscientists…?

We agree this could be confusing, so in line 19 of the abstract we have changed 'human interactions' to 'presence of humans', which is how we have loosely defined them. Later in the manuscript (lines 476-479), we are more specific in defining human interactions 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.' This is the definition we found most useful during qualitative thematic analysis of the sketches.

23 mental models in general, or mental models of geoscientists vs. non-geoscientists? Be careful to keep your conclusions within the scope of what your study actually addressed.

Thank you, we have added 'of geoscientists and non-geoscientists' to line 30 to clarify this.

24 "both components need"?

Yes, we have added 'both components' to line 31.

37 understanding

We have changed the phrasing here from '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)' to 'A starting point from which to understand each other is to investigate the differences between geoscientists (defined as anyone with at least a university degree in geology or geoscience) and non-geoscientists (those without such a degree)' (line 68).

38 you use the term mental models before defining it; you should define it on first use.

We have changed the phrasing (see comment above) to make sure we define it on first mention (a very simple definition is in the abstract, line 16).

38 defined for our purposes, or which we define for this study as – make it clear that you are the ones defining it

We have added 'for our purposes' (line 72).

41 correct the grammar (need a connecting word after the ,)

Thank you – we have added 'or' as a connecting word (line 72).

43 is the concept of mental models specific to the geosciences?

No, quite right. We have clarified that this study (Libarkin et al) looked at mental models 'in the context of science education' (line 75).

44 I'm not clear on how these models differ; examples would help

We have added examples to clarify this. Specifically, we have rephrased to: ‘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 (for instance, aquifer models); “conceptual frameworks”, organised and stable models of the world used by geoscientists (for instance, the notion of gravity); “naïve mental models”, intuitive models of the world that so-called ‘novices’ fill with fragmented and unconnected knowledge (for instance, the notion that the Earth is flat); and “unstable mental models”, unstable, incomplete and inexact mental models which are used by novices and easily modified (for instance, the idea that the Earth is spherical, but with flattened portions where humans live)’ (lines 75-89).

[54 – 72 have been replaced]

73 contribution = goal?

Yes, we have changed this (line 154: ‘the main goal of the present study’).

73-80 this would benefit from acknowledging some of the specifics of this study, acknowledging that this study; a study of this limited scope cannot aspire to investigate this issue for all of geoscientists and non-geoscientists in all settings (and indeed, how mental models vary between different types of geoscientists, different demographics, and communities with different experiences would all be interesting questions to explore)

Yes, we agree and do not wish to claim to generalise to all geoscientists and non-geoscientists. We have rephrased (lines 164-167): ‘While our sample of geoscientists (n=24) working across Ireland and non-geoscientists (n=38) recruited in a rural community in Ireland is not representative of all geoscientists and non-geoscientists in all settings, we suggest that understanding differences and resemblances of both the cognitive and affective components of mental models of geoscientists and non-geoscientists can help to improve two-way communication between them about often-contested areas of the geosciences.’

76-80 introducing an argument in your introduction, rather than posing this idea as a

hypothesis or question, gives the strong impression that you entered your study with a preconceived / expected outcome

The rephrasing in the point above solves this issue.

83-85 again, this needs to acknowledge the specifics of the study

We have added 'Irish' here in this introductory sentence (line 171), and more details of sample make up are just below (line 173).

94-95 this is unclear

We have added details about the design as follows (lines 181-184): 'In our analyses, we used a mixed experimental set-up of between-subjects design (to compare geoscientists vs non-geoscientists) and within-subjects design (to investigate sketches of subsurface, drilling, mining/quarrying, flooding within our sample group of geoscientists or non-geoscientists).'

97 which beliefs?

We have clarified that this refers to 'beliefs about the subsurface and geological activities' (lines 194-195).

97-98 subject-verb agreement

Thanks, we have fixed this.

98 is there a reference for the qualitative thematic analysis technique?

Yes, we have added references here (line 196): '(Boyatzis, 1998; Marshall and Rossman, 1999).'

99 the IBM

Thanks, we have fixed this.

108 speak to range as well as majority

We have added details on the range: 'The geoscientists who took part in the study ranged in age from 21 to 59' (lines 203-204) and, for non-geoscientists, 'their age ranged from 16 to 60 or Over' (lines 207-208).

110 Table 1 – why did you include income and household type?

Thank you for pointing this out. We gathered this as part of our sociodemographic data but did not analyse it or use it in reporting our findings. We have removed it.

125 name specific university

We have edited this to say ‘University College Dublin’ (line 231).

133 (n=11), and

We have added ‘and’ (line 238).

145 quarrying, and flooding - the Oxford comma will make this much easier to understand (I recommend applying it throughout the manuscript)

Thank you, we agree. Have made this change throughout.

147 follow-up

We have made this change (line 254).

150 is there a word missing?

Yes, ‘for’ was missing. We have added this to line 257.

152-153 is there a word or phrase missing? Or ranging -> range?

Yes, ‘were measured’ was missing. We have added this now to line 259.

154 including flooding? I believe you have taken flooding out of your current draft; if so, ignore comment

Indeed, we have deleted flooding out of the current draft and removed the quantitative sketch analysis and explain why. We still include a description of what we have done, including the questions on flooding which yielded significant results, in the Materials and methods section, lines 256-258, where we have added: ‘Flooding did not yield reliable scales for affective responses or significant results for perceived impact, hence it was excluded from further analyses and from the rest of the results.’

159-163 rearrange sentence for clarity

This has been done and changed to ‘They indicated which feeling they identified with.. etc.’ in lines 266-267.

164 (2018), and

We have made this change (added ‘and’, line 271).

165 “formed both reliable scales” – unclear what this means

This is based on statistical analysis using Cronbach’s Alpha. Changed to ‘both formed reliable scales (Table 2), which is indicated by scores of Cronbach’s Alpha of 0.70 or higher (Peterson, 1994).’ – line 272-274, and added the reference to the Reference list.

169 Mean (M) and Standard Deviation (SD)

Added this to line 290.

169 use of title case (or not) should be consistent throughout

We have fixed this in Table 2.

169 why not list perceived impact and affective responses in the order in which they appear in the table?

We have done this.

170+ reformat table for readability

We have done this.

179 authors

We have made this change (line 301).

184 remove ,

We have made this change (line 316).

186 indicators, Independent

We have made this change (line 318).

187 the IBM

We have made this change (line 319).

192 variables ?

Yes, we have fixed this (line 325).

195 non-geoscientists in regard to…

We have added that the tests were run to compare ‘cognitive and affective responses of geoscientists and non-geoscientists (line 328).

200 interactions in regards to what?

We have rephrased to ‘human interactions (presence of humans in the sketches)’ in order to explain what this means. A more complete definition is at the start of the section on Human Interactions (line 475).

201 in the sketches only? Or through the sketches and interviews? Here you refer only to the sketches.

Good point, in the sketches and written comments on the survey (added to line 331).

217 0.006], and more

We have taken out the statistical test results from this paragraph (about the ANOVA repeated measures test) because we decided to remove the quantitative analysis of the sketch analysis once we removed flooding.

219 remove ‘ as non-geoscientists refers to the people, not their sketches

As above.

221 Fig 1a or just Figure 1?

Good point: ‘Figure 1’ is correct (line 351).

224 comments and sketches ?

Yes, we have changed this (line 406).

227 from an anthropocentric

We have made this change (line 409).

223 remove (Fig. 1b)

We have made this change.

240 denoting is probably the wrong word here

Good point, we have changed to ‘indicating’ (line 446).

240-241 among whom, and in what context?

Upon further consideration, we have decided to remove this sentence ('This sense of unfamiliarity with the subsurface and geological timescales was also noted by Stewart (2016)'), since the study mentioned was more related to sustainable geoscience and not as relevant to our finding about non-geoscientists.

247 subject-verb agreement

We have fixed this.

254 is this reflecting different beliefs or different knowledge? On what do you base the difference in beliefs? It seems that non-geoscientists aren't expressing a difference in beliefs, but rather that beyond a certain point they just don't know. Or are you saying there are different beliefs within both groups?

This is an interesting point. We agree it is probably more appropriate to use the term knowledge here, incorporating the idea of technical knowledge and lay expertise. Beliefs is a term more appropriate later on in the manuscript when talking about environment and economy, for instance. We have rephrased as follows (lines 456-468): '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 both geoscientists and non-geoscientists are complex and reflect different knowledge in both groups.'

257 quarrying; and g,h

We have fixed this and changed this part of the caption (line 474) to 'g,h, subsurface (left) and mining/quarrying (right).'

264 repeated measures analysis ?

We have removed this paragraph as it was part of the quantitative sketch analysis.

264 what does main effect mean? Is this a known social science construct?

We have removed this paragraph as it was part of the quantitative sketch analysis.

267 these are human, not geological processes – this is a significant distinction, as humans play an essential role in drilling and mining/quarrying, where they (we) may play no role in geohazards such as flooding. It's important to consider this in the interpretation of the mental models.

Yes, thank you for pointing this out. Indeed, these are human processes. We recognise that this is important in interpreting our results and have noted this in our interpretation (e.g., lines 490-493 of annotated manuscript: '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.'). We have also changed the word 'processes' to 'activities' throughout the manuscript to better reflect this point.

283-284 this seems like a stretch. The physical acts of mining/quarrying and drilling are not research endeavors in the same way that basic research is. They are focused on the human process and not on the Earth process (which would be, e.g., sedimentation, compaction, metamorphism, orogeny, etc., not mining or drilling)

We have removed this sentence.

286 again, they are human, not geological, processes

Noted (see our responses above).

295-300 cannot generalize your findings to all geoscientists; change have to had (x2: 295, 297)

We have made this change (lines 525 and 527).

307 negative responses to what?

We have deleted this paragraph.

309 that the geoscientists of our study have

We have deleted this paragraph.

312 what would geoscientists' affective response have to do with their misperceptions of

others? Is there evidence that they do misperceive the affective responses of nongeoscientists?

Upon further consideration, this is unclear and have deleted this paragraph (i.e. the paragraph: '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.')

326 the non-geoscientists

We have made this change (line 580).

326-327 "relate their negative emotions with the negative impact of geoscience on the environment" - unclear what this means

We have changed this sentence to: 'it was clear that the non-geoscientists tended to associate negative emotions with the negative impact of geoscience on the environment.' - lines 579-580.

357 do you want to indicate gender?

Thank you for pointing this out, we have removed this as it is not necessary for the purposes of interpreting results and we wish to preserve anonymity (line 626).

367 tended

We have made this change.

368 tended

We have made this change.

371 acknowledge your sample set, not necessarily indicative of all geoscientists & nongeoscientists in all circumstances

We have changed to 'a sample of Irish geoscientists and non-geoscientists' (line 646) to make this clear.

378 evidence? You have not argued this clearly yet

We have added this sentence to argue our point: ‘Indeed, we find that the mental models of both groups are complex reflections of different knowledge, beliefs and affect.’ (line 654-656).

383-384 move reference after “reality”?

We have done this (line 660).

394 this is a relatively strong unsubstantiated statement

Noted. We have changed to the sentence (line 677) to ‘As a practical step, in communicating with each other, geoscientists and non-geoscientists may wish to acknowledge their differences and focus on commonalities in order to find common ground’, as well as adding examples in the form of suggestions’ (also see below).

396-397 why, if they contract with those of non-geoscientists? Clarify your reasoning

Thank you for pointing out this was unclear. We have added the following (lines 679-685) by way of explanation: ‘For instance, given that both geoscientists and non-geoscientists are concerned with the impacts of geoscience on the economy and the environment and given that both groups incorporate affect in their mental models of geoscience concepts and activities, geoscientists may be able to reach wider audiences by acknowledging these concerns and affective components, and including feelings and affect in their chosen form of communication (e.g., personal motivations for their research).’

398 evidence? You bring the communications arguments in without substantial tie-in to the study or references. Consider statements such as “may benefit from” if you would like to make arguments.

See previous point, we addressed this in the sentences added above.

401-402 similarly, this is a very strong statement and referred to as a finding, when this is clearly an opinion; you have not addressed this issue in your study in any way, or if you have you have not made it clear through the description of your work

We have changed to: ‘In addition, geoscientists may benefit from using storytelling and narrative, which typically include both affective and cognitive components, as their chosen

modes of communication, a recommendation consistent with previous science communication research (Dahlstrom, 2015).' - (lines 685-688).

403-405 Why? Address this.

We have rephrased (lines 695-698) to: 'Given that non-geoscientists often incorporate lay expertise in their mental models, in order to build trust and common ground, 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.'

409 How about any benefits to geoscientists in recognizing the affective component of their mental models? Might it change how they see themselves as keepers of knowledge?

Thank you for this very interesting suggestion. We agree that this would be a benefit and have added this paragraph (lines 688-694): 'If geoscientists acknowledge the emotional component of their mental models, this may also lead them to reflect on the meaning of scientific knowledge and to change their view of themselves as keepers of knowledge. On one hand, this could influence how they communicate their work and activities to geoscientists and non-geoscientists, but it could also lead to a broader understanding of epistemology and the social component of geoscience on the part of geoscientists (see Stewart 2016).'

416 This is not a finding; of course, we are all human! Be more specific about what you mean.

We have changed our opening paragraph of the conclusions (lines 731-737) to: 'Our finding that geoscientists stray beyond facts into the realm of emotions and beliefs in constructing their mental models of geoscience concepts and activities is a key realisation for geoscience communication practitioners. We have argued that putting the human element at the centre of communication strategies will help achieve meaningful dialogue between geoscientists and non-geoscientists.'

Additional changes:

-We have changed the term ‘processes’ to ‘activities’ throughout the manuscript, to be more precise since, as rightly pointed out by the Editor, mining/quarrying and drilling are human - activities and not geological processes (such as metamorphism, orogeny, etc).

-We have altered Fig. 1g,h (following the removal of flooding from the image).

Reply to Editor and Referees (submitted on February 2020)

Dear Editor,

Thank you for your time and consideration of our work. We wish to thank the referees for a thorough and helpful analysis of our findings. Below, we have responded to each point made by the referees, indicating proposed changes we wish to make to the manuscript. We have indicated the page and line number of the original manuscript where the proposed changes apply (e.g., (3/23) = page 3, line 23). Referee comments are included in italics in the left column of the table below, followed by our responses and changes in the manuscript in the right column below.

Thank you and best wishes,

Anthea Lacchia on behalf of all authors

Responses to Referee Comments
Response to Anonymous Referee 1

Referee comments	**Response from authors and changes in the manuscript**
"Thank you for the opportunity to review this article, which has the potential to make a useful contribution to the field of geoscience communication. The paper is based on a sound idea and appropriate methods, but it needs work before it will be ready for publication."	We thank Referee 1 for the positive response to the idea behind this study and its methods. We in turn have found this review very helpful and informative.

"Much more engagement with the literature around perceptions of geosciences is necessary."	We agree with Referee 1's suggestion and have made use of the detailed and useful list of references provided both within and at the end of the review, many of which are now included in the manuscript. We have also added further references beyond those suggested. We detail the suggested additions to the manuscript below, grouped according to the suggestions made by Referee 1.
"For example, for expert and lay perceptions of underground geology see Partridge et al (2019); Seigo et al (2014)."	We read both papers with interest. We include a reference to Partridge et al (2019) in the section on Impact on Economy and Environment, and a discussion of Seigo et al (2014) in the introduction. Specifically, we have altered the introduction to include more literature discussion, as follows (3/31): "However, geoscientists often struggle to communicate with non-geoscientists, particularly around controversial topics such as resource extraction and risk communication. For instance, past studies have investigated public perception and risk communication in the case of fracking (e.g. Boudet *et al*., 2014; Thomas *et al.*, 2017), carbon capture and storage (Seigo et al., 2014) and earthquakes (e.g. Marincioni *et al*., 2012). Specifically, in the context of earthquake risk communication, Marincioni *et al.* (2012) studied the case of the 2009 earthquake in l'Aquila, Italy, as a result of which 308 people died: the authors identified a lack of clear communication from the risk management authorities to the public in relation to earthquake prediction and structural resistance of buildings. In the context of public perception of carbon capture and storage, Seigo *et al.* (2014) compared risk and benefit perceptions of the technology in different Canadian regions, and found that predictors of risk perceptions, such as sustainability concerns, did not vary across different regions and were unrelated to familiarity with the technology. The authors also point out that there is a need to address lay people's "misconceptions" related to carbon capture and storage, in order for informed decisions to take place. In the context of a public perceptions of fracking, Thomas *et al*., 2017, in a literature review, identified mixed levels of awareness of shale operations, as well as ethical issues and widespread distrust of responsible

	parties. Other studies concerning fracking, such as that by Boudet *et al.* (2014), which looked at public perceptions of fracking in the U.S., found differences in perception between different genders, socioeconomic backgrounds, income levels and level of education, and highlighted a need for "wide ranging and inclusive public dialogue" around the risks and benefits of fracking. We have added the following to (20/363): "In line with previous studies of perceptions of the underground (Partridge *et al*., 2019), we recognised tensions between economic values and environmental values in comments written on the survey, such as "*Drilling for a well for water is ok. Drilling for oil or gas is not necessary. Invest in solar and wind energy alternatives. Fracking is just idiotic*." Such comments tended to equate fracking with a threat, associated with fear. Another participant wrote: "*Concerned about fracking if not properly supervised*". This tension may be linked to a desire for control (cf Hooks *et al*. 2019) and regulation of geoscience activities and technologies (e.g., GSI, 2016), as typified by comments such as "*Concerned about fracking if not properly supervised*" or "*Groundwater pollution with farming practices, I would like it to be more controlled*." Geoscientists, while indicating an awareness of the negative effects of geoscience on the environment in written comments on the survey, generally downplayed *etc*." [as before]
"The conclusion that mental models are the result of beliefs that include both cognitive and affective components is not new. In two of the papers that you cite for example, the authors describe a number of 'nonknowledge' factors that contribute to risk perceptions – and you need to engage more with this literature (Sjoberg et al, 2007; Thomas et al., 2015)."	We agree that the papers dealing with emotions and risk perceptions should be highlighted clearly in our paper and propose altering and adding to the introduction to mental models literature from (3/54) to (3/72) as follows: "Mental models have previously been used to understand non-experts' perceptions of geoscience-related topics. For instance, Bostrom *et al.* (1994) investigated non-experts' mental models of climate change, and found that global warming was regarded as "both bad and highly likely". Zaunbrecher *et al.,* (2018), investigating non-experts' mental models of geothermal energy, identified varying attitudes and knowledge levels among participants, with negative emotions being evoked by the concepts of drilling and

	power stations. These studies also stress that there are emotional or affective components underlying the mental models of non-experts. However, most mental models studies 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). The role of emotions in risk perception and communication around nuclear waste has been investigated by Sjöberg (2007), who argued that emotions such as interest play an important role in risk perception and attitude. In Zaunbrecher *et al*.'s (2018) study of public perception of geothermal energy, an association between positive emotions and the acceptance of geothermal energy was identified. Similarly, Thomas *et al.* (2015) identified negative emotions in the mental models of non-experts when considering sea level change. While these studies recognise emotions as a component of the mental models of non-geoscientists, far less is known about the affective responses of geoscientists, and how they influence their mental models, as well as how they compare with those of non-geoscientists. Compared with the number of studies focusing on non-experts or publics, fewer studies have used mental models to compare experts' and non-experts' perceptions. For example, Gibson *et al.* (2016) identified mismatches in perceptions of subsurface hydrology and geohazards between experts and non-experts. In a study comparing experts' and non-experts' mental models of nuclear waste, Skarlatidou *et al*. (2012) described non-experts' negative perceptions of nuclear

	waste as co-existing with a positive attitude towards nuclear energy, as well as lack of knowledge and familiarity, and discussed implications for risk communication. In the context of sea-level change, Thomas *et al.* (2015) identified both consistencies between the mental models of experts and non-experts, and barriers to publics engaging with the issue, and argued that factors other than knowledge bear an influence on the mental models of non-experts. These factors include "levels of concern, perceptions of self-efficacy and responsibility, trust and ways of actively engaging with or avoiding the issue" (Thomas *et al.*, 2015, p.78).
"The conclusion that experts are 'human' and have affective responses is also not new: see for example Wynne (1996) for a discussion of lay expertise. Some critical engagement with what constitutes expertise would also be helpful – see for example Collins and Evans (2002)."	We have added a section devoted to lay expertise (which we include in this response to Referee 1 below).
"There are major biases in your sample: the geoscientists are much younger, largely students, predominantly male, and highly educated. How do you know that your results are not a function of these differences rather than the fact that they are geoscientists? A wealth of research shows that risk perceptions vary with age, gender etc – and this should be taken much more into account, as this raises serious questions for your results and conclusions."	We recognise that these factors relating to our sample could introduce bias and affect our results. The makeup of our sample of geoscientists was also mentioned by Referee 2. Given these limitations, we agree with the suggestion that it is helpful to focus more on our qualitative findings than we did in the original manuscript. We also suggest adding the following section at the end of our Discussion (22/408): "*Limitations* While this mixed-method study highlights differences and similarities between the mental models of geoscientists and non-geoscientists, it should be noted that the sample size is small, and thus our results need to be interpreted with care. Future research is needed to validate our conclusions. It should further be noted that the geoscientists who took part in this study were primarily highly-educated males working in applied geoscience research at the time the survey took place (only 2 worked outside of research), and they were younger compared to the non-geoscientists who took part (for details,

	see Materials and Methods). The latter is fairly representative for geoscientists (e.g., Dutt *et al.*, 2016), however, we cannot say with certainty that these differences in socio-demographics play a role in the differences we find. For example, female and younger geoscientists may hold different perceptions of geoscience activities and their impacts (cf. Seigo *et al*., 2014). However, this does not influence our main conclusion that geoscientists' mental models are influenced by both cognitive and affective responses." We also propose adding this sentence to the Method section (5/108): "We discuss the limitations associated with our sample in the Discussion section."
"You have some interesting qualitative findings here that deserve much more discussion. For example, what local knowledge was included? What can this tell us? What is the significance of this? Why did experts include more labels – is this anything to do with fulfilling what was expected of them? Perhaps they enjoyed it more than the lay participants so wanted to provide as much information as possible? Are geoscientists more practised in drawing diagrams, and might this explain the attention to detail? Does the amount of detail in the pictures reflect a lack of understanding or a perceived lack of understanding (the 'I'm not a scientist so I don't know' phenomenon. . . - see for example Bickerstaff et al 2006; Michael, 1992). Is it indifference or ignorance? There are so many things here that I would like you tell me more about. Due to the nature of your sample, I think it is difficult for you to focus on the quantitative results, but you could certainly explore your qualitative results more."	We thank Referee 1 for their helpful comments. We agree that our qualitative results merit further emphasis. In our revision, we wish to retain our quantitative results relating to human interactions, affective response and impact on economy and environment, as they are a useful exploratory tool, but to focus more on qualitative results. In particular, we propose describing the sketches from a qualitative point of view, which allows us to explore interesting themes such as lay expertise. (12/203): we wish to change the heading from 'Technical knowledge and familiarity' to 'Knowledge and expertise' so as to better reflect the lay expertise now discussed. We also suggest adding subsections on 'technical knowledge and familiarity', and on 'lay expertise', and one entitled 'Concluding remarks'. We include below our new proposed section entitled 'Knowledge and expertise': "**Knowledge and expertise** *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, the sketches made by geoscientists extended down to a greater *depth*, included more *technical jargon* related to geoscience, more *labels*, more *layers*

	within the Earth's interior, and a greater *sense of scale*, compared to those of non-geoscientists (Fig. 1a). For instance, it was common for geoscientists to extend their sketches down to the mantle and/or core. It is not surprising that geoscientists included these indicators of technical knowledge in their sketches given that drawing and sketching the landscape and the Earth's interior are skills typically acquired during geoscience undergraduate education (Johnson & Reynolds, 2006) and given the importance of spatial visualisation as a geoscience skill (Titus & Horsman, 2009). Without being prompted to do so, some geoscientists also included colours and colour-coding in their sketches, which is another habit likely to have been acquired during undergraduate geoscience training and thus linked to technical knowledge. Geoscientists may also have enjoyed the task of sketching to a greater extent, wanting to provide as much information as possible: for instance, a sense of enjoyment was reflected in the inclusion of smiles on the faces of stick figures in one geoscientist's sketch, which also included different types of fossils and crystal shapes (Fig. 1g). It was not uncommon for geoscientists to include exclamation marks in their labels, such as "*Hawaii!*", indicating engagement with the process of sketching and enjoyment. A greater degree of technical knowledge and familiarity with geoscience in the sketches of geoscientists is consistent with the assumption that geoscientists have "conceptual mental models", which are developed based on their expertise and training in geoscience. Conversely, the lower levels of detail and technical knowledge in the sketches of non-geoscientists may reflect lack of knowledge but may also be linked to a lack of interest in the topics or a perception of science as inaccessible and exclusive. The notion that science can be viewed as a distant and inaccessible entity by non-scientists was identified in previous studies of public perception of risks (Bickerstaff *et al*., 2006; Michael, 1992). Furthermore, 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. Religious belief systems also surfaced among participants, with one non-geoscientist stating: "[…] *we disagree on that [that ammonoid fossils are much older than humans]. I believe in the genesis and that humans arrived at the same time as animals*." In this case, these beliefs were deemed by the participant to be in opposition to the science and specifically to the geoscience concept of geological time which the survey brought to the fore. *Lay expertise* The non-geoscientists' sketches contained indicators of local knowledge about their own area (Fig. 1b), which we interpret as lay expertise (e.g., Cronin *et al.* 2004; Wynne, 1996). Lay expertise is here taken as a form of knowledge that is relevant to and can contribute to the scientific discourse (see Collins & Evans, 2002). For example, one non-geoscientist's sketch (Fig. 1h) of mining/quarrying included historical details, such as the historical ownership of mines by "*Judge Comyn*" and the "*government*", as well as the location of historical phosphate mines and the past site of "*surface mining and blasting*". Another non-geoscientist noted the presence of a "*water reservoir on top of Black Head*" in a comment written on the sketch, while also adding at the end of the survey: "*Having lived in Meath for 20 years, I was aware of mining in Tara Mines and the creation of Newgrange Visitor Centre*." In addition, a non-geoscientist included the subsurface depth beneath which water could be found in their local area, alongside the label: "*Drilling for water around Kilkee area. Good supply found*". 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*". This sense of uncertainty may also be linked to the sense of distance from science viewed as exclusive and inaccessible already described. *Concluding remarks* In conclusion, 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." We suggest modifying the sentence at (8/141): "The survey was aimed at qualitatively assessing underlying beliefs of respondents' mental models of the subsurface, drilling, mining/quarrying, and flooding. This qualitative analysis was supplemented by quantitative analysis of survey responses." We also wish to add the following line at 11/188: "These results informed our qualitative analysis of the sketches."

	Since we no longer focus on the quantitative results, we wish to move the paragraph starting on (12/208) and ending (12/214) to the method, at (11/180), and delete from (11/182) to (11/184). We also wish to add 'lay expertise' to this sentence of the abstract to highlight our findings (1/20): "While the mental models of non-geoscientists focus more on the perceived negative environmental and economic impacts of geoscience, as well as providing evidence of lay expertise, those of geoscientists focus more on human interactions."
(2/29) provide some examples of why geoscience is integral in society e.g. mining, risk management, landscape management, etc. etc.	We suggest changing (2/29) to: "Geoscience activities such as mining, quarrying, hazard risk management and landscape management are an integral part of society, affecting local communities, citizens and scientists."
(2/33) provide examples of problems with geoscience communication, such as with fracking and geohazards (e.g. L'Aquila earthquake).	We have added the example of risk communication related to earthquakes and the example of L'Aquila to the introduction (already mentioned above).
(3/54-55) the term 'expert' would be more appropriate than 'geoscientist' as not all of this research looks at geoscientists.	We agree and have replaced the terms 'geoscientist' and 'non-geoscientists' with 'expert' and 'non-expert' in this sentence.
(3/65) as the authors do in Thomas et al (2015, cited above).	Our revised introduction adds this.
(19/334) you mention lack of trust – you could relate this with previous research that also discusses lack of trust in geoscience industry (e.g. Thomas et al., 2017).	We wish to add this sentence to (19/335): "Lack of trust in industry and government has previously been identified as a dominant theme in a review of public perceptions of hydraulic fracturing for shale gas and oil (Thomas et al., 2017)."

Response to Anonymous Referee 2

Referee comments	**Response from authors and changes in the manuscrips**
"This paper presents new data concerning the contrast in perceptions of geoscience between geoscientists and the lay public, highlighting the role of affect in a mental models approach. The results present an interesting view of an important topic, namely the role of identity and emotion in influencing risk communications between experts and non-experts. Though the results of the paper are interesting, I have some questions regarding the nature of the study that I think need answering before publication."	We thank Referee 2 for these positive comments about our study and for providing a very helpful review.
"Firstly, the authors present data in response to the stimulus to "sketch the ground beneath your feet" and then "make sketches of drilling, mining/quarrying and flooding" and these results were analyzed collectively, except for the affective component, where the flooding data was missing. My question is about the inclusion of the flooding data in the analysis at all. Firstly the dataset for flooding is not complete, given the missing affective survey results, and secondly the type of hazard here is very different to those anthropogenic hazards of commercial geoscience. Thus, unless another (more natural) hazard was also included (such as landslides?) as a comparison, it feels like the stimulus would be related to different conceptualizations of risk and that would confuse the final results."	Referee 2 is correct in pointing out that flooding was omitted from the affective component analysis. We wish to also point out that it was also omitted from the analysis on impact on the economy and environment. Upon consideration, we agree that flooding, as a hazard, is quite a different category to mining/quarrying and drilling. The comparison with landslides would have indeed been interesting but beyond the scope of this paper. With this in mind, we omitted flooding from the sketch analysis (described at 10/175), when looking for differences between geoscientists and non-geoscientists (based on the indicators number of labels, layers, sense of scale, technical jargon and depth) and re-ran the ANOVA Repeated Measures analysis, but the multivariate tests were not always significant ($p \geq 0.05$) without the flooding data. We thus propose removing the quantitative sketch analysis from our paper, focusing instead on qualitative analysis, and removing flooding from the results altogether so as not to confound results. **Proposed changes in detail:** Delete (11/179) to (11/187) since results are to be discussed qualitatively. Delete 'flooding' from the manuscript in the following lines and pages: 1/17; 9/154; 9/159.

	Propose deleting sketches g,h from Fig. 1, and substituting them with examples of a geoscientist's sketch showing stick figures with smiling faces, and a non-geoscientist showing evidence for lay expertise. Modify 8/149 to: "Flooding did not yield reliable scales for affective responses or significant results for perceived impact, hence it was excluded from further analyses and from the rest of the results." Delete the following paragraph from 'human interactions', 16/264: "An ANOVA repeated measures revealed a significant main effect of human interaction across the sketches of drilling, mining/quarrying and flooding, (Wilks' λ = 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), ($p \leq 0.001$). " Since we re-analysed the data without flooding, we wish to modify the sentence starting with 'interestingly' at (16/268) to the following: "Interestingly, geoscientists included more human interactions than non-geoscientists when sketching drilling, [$t(56) = 3.77$, $p \leq 0.001$] and mining/quarrying, [$t(56) = 3.14$, $p = 0.003$]."
"Secondly in the presentation of the affective beliefs of the geoscientists, the authors state that "the geoscientists have more positive affective responses to mining/quarrying", etc and I am curious how much of that was related to their employment within those fields? It has been shown (such as in Mearns and Flin, 1995) that people working in an industry are more likely to operate from within	Our sample of geoscientists was mainly made up of people working in research concerned with applied geoscience such as mining/quarrying, though we did not formally gather this data. Though these people were not directly working in those industries, it is indeed possible that this could have affected their risk perceptions and also their affective responses. Otherwise, the notion that the

their own specific and subjective risk framework which is often more positive about the risk than the objective assessment would be, particularly as beneficial employment prospects contribute to mitigating the perceived risk. Therefore if those geoscientists surveyed worked in mining and quarrying fields, it is reasonable that their more positive assessment of the activity could equally be related to their employment, which would be useful information in the context of this study."	profession of geoscientists (and their interest and enjoyment) would affect our results was actually one of our hypotheses: that geoscientists would differ from non-geoscientists due to their profession. To discuss this further, we propose adding the following to (18/312): "It should be pointed out that many of the geoscientists in our sample worked in research in geoscience activities (though area of research was not formally gathered), which could have resulted in more positive affective associations with their field of research, such as feelings of safety (cf. Mearns & Flin, 1995)."
"Additional notes: Line 75: open parenthesis"	We have fixed this typo.