Reply to Editor and Referees

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	We thank Referee 2 for these positive comments about our study and for providing a very helpful review.

regarding the nature of the study that I think need answering before publication."	
"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 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."	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 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 also 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.