

Author comments in response to reviewer one:

Thank you very much for your comments, which I will address below:

1. Thank you for this comment – I have attempted to address the issue of language, particularly the use of heuristics and snowball sampling.
2. Yes I agree, and an example of how poor communication can lead to misconceptions has been added: p2 line 70-76
3. Thank you for this comment, some additional detail has been added to clarify the meaning of this diagram: p5 lines 192-196
4. This is a very interesting suggestion, thank you. Although it would be useful to suggest an alternative method for communicators and geologists who don't have the time to complete the full method, the central aim of this paper is to make a case for using the mental models method to improve the quality and relevance of communication between both expert and non-expert parties. As such I don't feel that I can offer a shorter or more compressed version of this method without doing a disservice to the process.

Additional comments:

P1 line 32 – yes, this has been altered

P2 line 44 – yes, a sentence has been added to clarify the meaning of heuristics (line 46-47)

P2 line 77 – yes, an example of the messages have been added (line 97-101)

P7 line 212 – yes, additional information has been added to clarify (line 248)

P7 line 224 – no, a single questionnaire is produced, additional information has been added to clarify (line 257-262)

P8 line 252 – hydrological interactions were chosen because they were unexpected, additional information has been added to clarify (line 309-311)

P8 line 260 – yes, this has been altered

P9 line 287 – yes an additional sentence has been added to provide more information about snowball sampling (line 353-357)

P13 line 403 – yes, this is an error – there is an image for 3e, but this reference does not refer to it (also this figure has been changed to Figure 4)

P 16 line 529 – yes, thank you, this was confusing – it has been altered (line 622)

Figure 1 – yes, this has been altered (Figure 1)

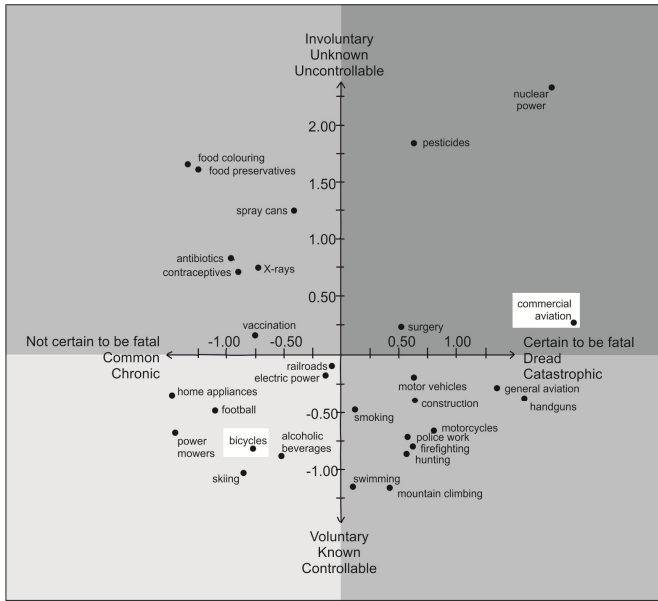


Figure 3 – yes, this has been altered (is now Figure 4)



### Author comments in response to reviewer two

Thank you very much for your comments which I will try and address below:

In response to the statement about the influence of formal education as providing a 'base level of knowledge that scientists can relate to': I agree, formal education does provide data that the non-expert participant will use in decision making that may be considered more familiar to a scientist, but it is unlikely that that information from a formal educational background will not also be influenced by the participant's own perceptions of their environment. Thus formal educational experience (to whatever level or degree of participation) is included within the broad description of the inherent cultural and social influences that control participant interpretation of new scientific data. Additional detail has been added to clarify this point (line 93).

In response to the statement about the use of analogy: As the mental models method allows for participants to share intuitive theories in their own words during the interview stage, analogies are included in the model, however the method of the interviews also allows for the interviewer to probe certain statements in more detail if required and as such it is possible to discover if the analogy is covering another perception, or if the analogy represents an actual concept for the participants. As such, the use of analogy is not considered directly relevant to this study, as they are either exposed or incorporated into the model itself. However, addition detail has been added to clarify this point (line 251-252).

In response to the comment for clarification of the expert dismissal of the relevance of lay-knowledge: the sentence has been clarified to preclude individual communications, which do often value local knowledge, and clarify the classification of the non-expert approach as inappropriate in relationship to the study done by Johnson (2008) examining public participation in watershed modelling (line 154-159).

In response to the question about the place of deductive reasoning in decision making: I agree that there are other types of reasoning that are involved with decision making and have clarified the sentence to make this more clear (line 176-178).

In response to the query for more data on how the semi-structured interviews and quantitative questionnaires have been designed: yes, additional information has been provided (line 359-374).

In response to the question about the decision to employ a 3D participatory model: additional detail has been provided to clarify the inclusion of the model (line 271-276). Additionally the use of a computer model would not be suitable for issues of practicality.

Minor comments:

Line 37 change : yes, this has been altered (line 39)

Figure 2: yes, the font size has been increased as much as possible (Figure 2)

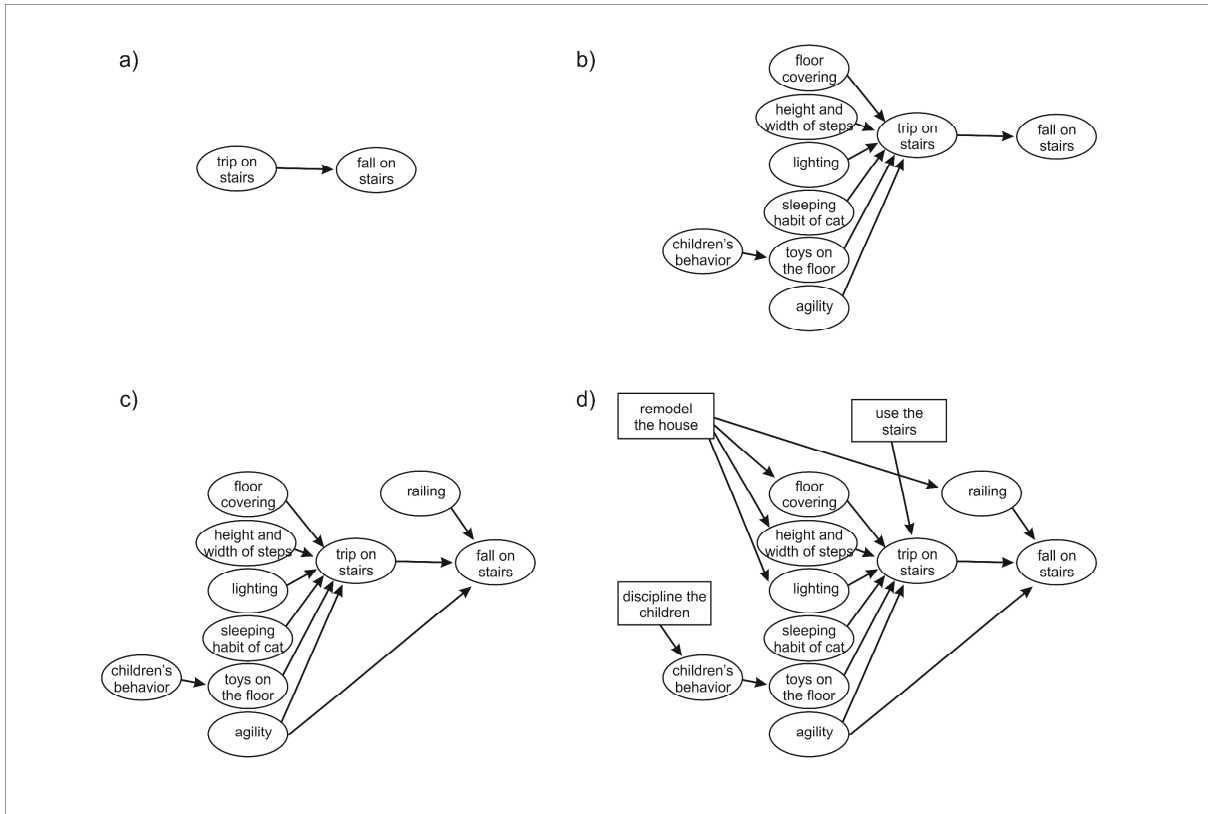


Figure 5: I have adjusted the contrast of both graphics to make them easier to see, but the coloured portion is the more important data anyway ( now Figure 6 and Figure 7)

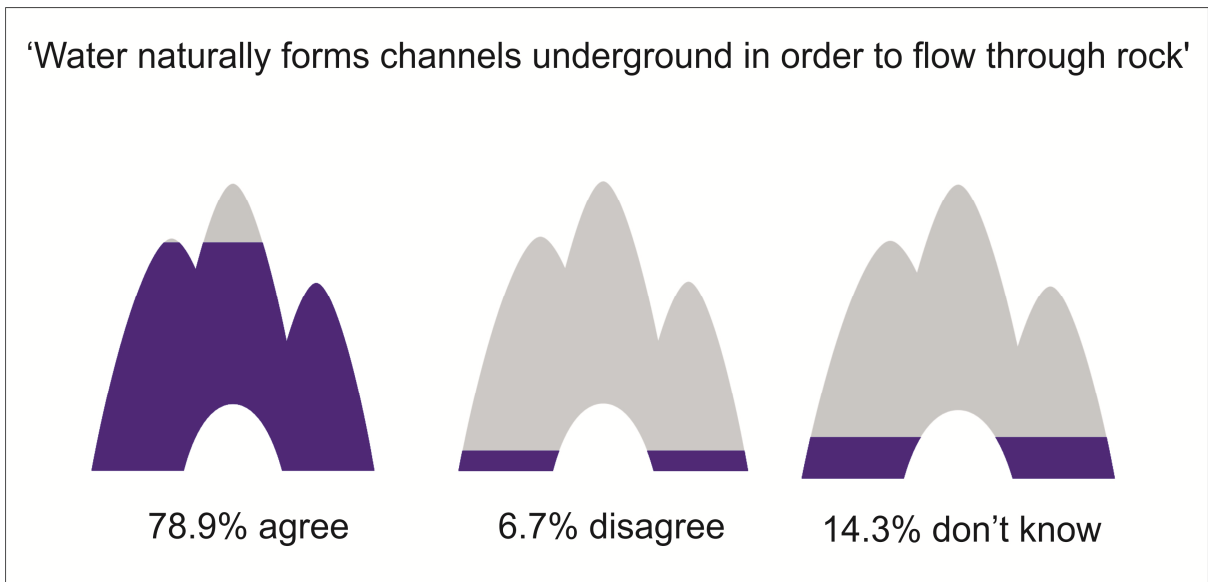


Figure 6

'Water cannot flow through solid rock'



28.6% agree



49.5% disagree



21.8% don't know

Figure 7

1 **A ‘Mental Models’ approach to the communication of subsurface**  
2 **hydrology and hazards**

3

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9

10 Abstract

11

12 Communicating information about geological and hydrological hazards relies on  
13 appropriately worded communications targeted at the needs of the audience. But  
14 what are these needs and how does the geoscientist discern them? This paper  
15 adopts a psychological ‘mental models’ approach to assess the public perception of  
16 the geological subsurface, presenting the results of attitudinal studies and surveys  
17 in three communities in the south-west of England ~~about their attitudes and~~  
18 ~~representations of the geological subsurface~~. The findings reveal important  
19 preconceptions and misconceptions regarding the impact of hydrological systems  
20 and hazards on the geological subsurface, notably in terms of the persistent  
21 conceptualisation of underground rivers and the inferred relations between flooding  
22 and human activity. The study demonstrates how such mental models can provide  
23 geoscientists with empirical, detailed and generalised data of perceptions  
24 surrounding an issue, as well reveal unexpected outliers in perception that they may  
25 not have considered relevant, but which nevertheless may locally influence  
26 communication. Using this approach, ~~researchers and communicators~~ geoscientists  
27 can develop information messages that more directly engage local concerns and  
28 create open engagement pathways based on dialogue, which in turn allow both  
29 ~~groups~~ geoscience ‘experts and local ‘non-experts’ to come together and understand  
30 each other more effectively.

31

32 1 Introduction

33

34 | Communicating ~~geological~~ information about geological and hydrological hazards  
35 | relies on appropriately worded communications (Liverman, 2010) targeted at the  
36 | needs of the audience (Nisbet, 2009). Those needs are often deemed to be what  
37 | geoscience professionals feel the public ‘need to know’, leading many hazard  
38 | messages to fall into the largely now rejected ‘deficit model’ of communication  
39 | (Sturgis and Allum, 2004). ~~According to this~~That model assumes people need to be  
40 | educated about those areas of knowledge in which they are seen to be deficient,  
41 | ~~rather than taking into account and ignores~~ their existing knowledge structures and  
42 | wider concerns or values. Moreover, the responsibility for tailoring the  
43 | communication to the target audience is often placed on the public, requiring them to  
44 | ‘ask the right questions’ (Rosenbaum and Culshaw, 2003). This emphasis on the  
45 | public’s need-requirement to ask the right questions misses a bigger issue in  
46 | communicating geological hazards, ~~which is namely~~ the influence of intuitive  
47 | judgments, such as heuristics (Gilovich et al., 2002), ~~and bias~~ in how people may  
48 | interpret information, especially unfamiliar scientific and technical data (Kunreuther  
49 | and Slovic, 1996).

50 |  
51 | The value in examining perceptions specifically is increasingly being recognised by  
52 | many in the risk communication community, including in disaster risk reduction and  
53 | commercial geology fields. Barclay et al (2008), for example, called for a more  
54 | interdisciplinary ‘disaster reduction’ approach to volcanic risk communication, which  
55 | includes stakeholders in policymaking, and uses social and physical science to work  
56 | together to produce more appropriate and effective communications based on the  
57 | needs of the community. Meeting the particular needs of at-risk communities through  
58 | collaboration between the physical and social sciences is now emerging as a fairly  
59 | central component of modern risk science (Donovan et al., 2012;Frewer, 2004;Lave  
60 | and Lave, 1991;Mabon et al., 2014).

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61 |  
62 | The subjective nature of risk communication and understanding ~~in-among~~ both  
63 | experts and non-experts is now well established (Slovic et al., 2004), but it is easy  
64 | for risk communicators to focus on improving access to information from the  
65 | scientists’ perspective, and overlook the impact of experience- and emotion-based  
66 | preconceptions from the non-expert perspective (Leiserowitz, 2006). Commonplace  
67 | preconceptions will strongly influence the way that a non-specialist will access and

68 interpret the geoscience risk information provided to them (Liverman, 2010), and so  
69 it is vital that public perceptions of geological and hydrological hazards are taken into  
70 consideration by communicators. An example of the importance of misconceptions  
71 is provided by Shackley et al (2004), who reports a geoscience expert using the term  
72 'bubble' of CO<sub>2</sub> (Shackley et al., 2004 p 127) to explain carbon capture and storage  
73 to a lay-audience; the result was a participant gaining a misconception relating to the  
74 storage of the carbon in the form of 'a large bubble' of gas which could burst at any  
75 time. This misconception caused some participants great distress and increased  
76 their perception of the risk.

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77  
78 ~~The value in examining perceptions specifically is increasingly being recognised by~~  
79 ~~many in the risk communication community, including in disaster risk reduction and~~  
80 ~~commercial geology fields. Barclay et al (2008), for example, called for a more~~  
81 ~~interdisciplinary 'disaster reduction' approach to volcanic risk communication, which~~  
82 ~~includes stakeholders in policymaking, and uses social and physical science to work~~  
83 ~~together to produce more appropriate and effective communications based on the~~  
84 ~~needs of the community. Meeting the particular needs of at risk communities through~~  
85 ~~collaboration between the physical and social sciences is now emerging as a fairly~~  
86 ~~central component of modern risk science (Donovan et al., 2012; Frewer, 2004; Lave~~  
87 ~~and Lave, 1991; Mabon et al., 2014).~~

Field Code Changed

88  
89 It has long been known that when the public receives information, they can interpret  
90 it - and therefore organise their reactions - in a variety of ways depending on their  
91 perception of both the science and the scientist (Fischhoff 1995). Various inherent  
92 cultural and social assumptions control the way that this information is interpreted,  
93 not excluding the influence of the individual's previous educational background  
94 (Donovan, 2010; Mabon et al., 2014; Slovic et al., 2007). Thus, without examining a  
95 population through social or psychological scientific inquiry, it is impossible to predict  
96 how they will respond to a particular science communication message (Wynne,  
97 1991). An example of the impact of the participant's background on a risk  
98 communication message was explored in a study by Keller, et al (2006). It was found  
99 that a person's background and experience, particularly of previous flooding events,  
100 had a significant impact on the severity of risk ascribed to a flood hazard  
101 communication.

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102

103 A key challenge of communicating such messages, therefore, is that in addition to  
104 the wider social or cultural impact on perception of scientific information, individuals  
105 apply their own pre-existing ideas and concepts to any scientific data that they are  
106 presented with (Mileti et al., 2004). In this context, psychology-based methods are  
107 vital, and one such method is the 'mental models' approach (Morgan et al., 2002).

108 This paper ~~outlines-introduces~~ the mental models methodology and ~~uses it to explore~~  
109 ~~broadly held~~~~presents empirical evidence for public~~ perceptions of the geological  
110 subsurface, ~~and from that examine~~~~making inferences about~~ how those perceptions  
111 relate to geological and hydrological hazards. ~~Empirical evidence is presented~~  
112 ~~showing that such a method can provide valuable contextual data for geological and~~  
113 ~~hydrological hazard communicators.~~

114

## 115 2 Communicating Risk via Mental Models

116

117 ~~Traditional-Conventional~~ views of risk communication have ~~conventionally~~ been  
118 based on how best to align the knowledge of the recipient with that of the expert (or  
119 communicator). Early work by Slovic (1987) demonstrated how several key factors  
120 underlie the perception of risk in non-experts, ~~notably concepts~~ such as 'familiarity'  
121 and 'dread' . A graphical representation (Fig 1) shows the relative perceptions of  
122 different threats, as organised by their varying degrees of familiarity and dread. The  
123 diagram shows that certain threats, which may statistically be considered more risky  
124 – such as riding a bicycle – are perceived to be far less risky than a statistically safer  
125 activity – such as flying in a commercial aeroplane (Slovic, 1987). Later work coined  
126 the term 'affect heuristic' to describe the important role of ~~intuitive~~ feelings in non-  
127 experts' risk assessments (Slovic, 2010;Slovic et al., 2004).

128

129

130 *Figure 1. The perception of risk within a two factor space, representing public*  
131 *perceptions of how risky an activity was based on its familiarity and how fatal the*  
132 *consequences may be (Slovic, 1987 p98).*

133

134 The affect heuristic describes the way that an individual's perception can colour their  
135 response to a piece of information about a subject, by ascribing greater or lesser

136 importance to the risk than an expert would, based on a logical assessment. The  
137 affect heuristic can be described as a form of emotion, defined as positive or  
138 negative feelings that are used to evaluate an external stimulus (Slovic et al., 2007).  
139 The influence of heuristics ~~and biases~~, such as the affect heuristic, ~~is~~ are so central to  
140 designing effective risk communication that these need to be far more fully ~~more~~  
141 integrated into methods of assessing the public's perception of geological and  
142 hydrological issues ~~need to be utilised~~ (Mabon et al., 2014).

143  
144 By taking into account the impact of a non-experts' perception of risk, the field of risk  
145 communication shifts from a one-way form of communication towards more of a  
146 dialogue. However, even within this more inclusive mode of communication, an  
147 outdated emphasis on the information and value judgements of the expert is still  
148 apparent (Sturgis and Allum, 2004). By this account the 'top-down' transfer of  
149 information provided by the expert must be translated by the emotional state of the  
150 non-expert (Slovic et al., 2004) and integrated into their own 'lay knowledge' (Callon,  
151 1999). ~~While experts may value~~ Lay local knowledge during individual  
152 communications, often the contribution of the non-expert population ~~is~~ generally  
153 dismissed as inappropriate by experts, who expect decisions to be made on the  
154 basis of relevant technical information. An example of this was found by Johnson  
155 (2008) in a study of watershed modeling and public participation, which showed that  
156 an over-reliance on technical method for constructing the watershed model resulted  
157 in a disconnect between the public and the technical modellers, as the model was  
158 perceived to be inaccessible, despite early public enegement. ~~but~~ there is,  
159 however, a growing acknowledgment of the role and value of individual and  
160 community knowledge, not just in collecting and compiling scientific data (Lane et al.,  
161 2011), but also in improving communications by countering the expert-imposed  
162 concept of risk (Lave and Lave, 1991). One psychological approach that has been  
163 employed effectively in communicating across a range of risky and controversial  
164 geological and hydrological issues is 'mental models' (Lave and Lave, 1991;Maceda,  
165 2009;Skarlatidou et al., 2012;Wagner, 2007;Thomas et al., 2015).

166  
167 The mental models approach to communicating risk (Morgan et al., 2002) is based  
168 upon the broader mental models theory, developed by Johnston Laird (1980) as a  
169 conceptual paradigm that encompassed new ideas about language and perception

170 in the burgeoning field of cognitive science. The theory of mental models as  
171 interpretation of theoretical reasoning has fallen from favour in psychology (Evans,  
172 2002;Over, 2009), but it is still used in the applied sense, particularly by researchers  
173 examining decision making associated with risk, communication and education  
174 (Goel, 2007;Larson et al., 2012;Panagiotaki et al., 2009;Skarlatidou et al., 2012).

175  
176 The mental models approach to risk communication ~~employs~~ a form of deductive  
177 reasoning, one of the multiple types of reasoning which is connected ~~to~~-with decision  
178 making (Eysenck and Keane, 2010). The approach assumes that, in order to make a  
179 decision about an issue, an individual will construct an artificial (mental) reality in  
180 order to test a series of simulated scenarios using data previously collected and  
181 valued by that individual (Morgan et al., 2002). The decision about what action to  
182 take will be based upon a logical interpretation of the results of these tests, and  
183 decisions are most easily made when the tests are simple (Johnson-Laird, 2013).

184  
185 This method can be demonstrated by considering the decision of 'travelling down  
186 stairs'. Whilst it may seem an exceedingly simple issue, by considering all the  
187 different factors that might cause you to trip on the stairs and therefore what you may  
188 have to do to control those factors, a researcher can build a model of what a person  
189 considers when they are thinking of walking up or down stairs (Morgan et al., 2002).  
190 This simple example, represented in Fig. 2, demonstrates the particular  
191 effectiveness of mental models. In the diagram, some factors such as the floor  
192 covering, lighting or the height and width of the stairs may be anticipated by experts  
193 (for example an architectural designer, or specialist in home risk), and statistically  
194 assessed as being valuable factors to communicate hazards about. The node that  
195 mentions 'sleeping habits of the cat' however may not have been considered, and  
196 yet might be a key issue for a non-expert who lives in the property in this  
197 circumstance.

198  
199 The use of mental models, therefore, allows the researcher to gain a better  
200 understanding of the importance of many issues from both the expert and non-expert  
201 perspective, and also allows for the inclusion of not just analytical reasoning, but  
202 experiential as well (Leiserowitz, 2006).

203

204

205 *Figure 2. Illustration of the construction of an influence diagram for the risk of tripping*  
206 *and falling on the stairs: a) shows just those two elements; b) adds factors that could*  
207 *cause a person to trip; c) adds factors that might prevent a fall after a person trips;*  
208 *and d) introduces decisions that a person could make that would influence the*  
209 *probabilities of tripping and falling (Morgan et al., 2002 p37).*

210

211 In the context of geological hazards and risks, it was found that in cases where the  
212 risks are unfamiliar to the individual, mental models theory allowed the participant to  
213 explore the decision-making process more fully (Goel, 2007). When applied to  
214 specific contexts, most notably to radioactive waste management and carbon  
215 capture and storage (Skarlatidou et al., 2012;Vari, 2004;Wallquist et al., 2010), it was  
216 found that in cases where the perceived risk of new technology was greater than the  
217 actual risk (or the risk designated by the expert), mental models provided a useful  
218 holistic approach to decision making, that placed equal value on the attitudes of both  
219 expert and non-expert (Vari, 2004).

220

221 An important aspect of the mental models approach is in the equivalent value placed  
222 on the data coming from the non-expert. In placing the non-expert in a position of  
223 equal authority with the expert, any information provided is also represented as  
224 equally-being just as important (Morgan et al., 2002). This draws the communicator  
225 away from the one-directional deficit model of communications (Bucchi, 2008) and  
226 towards a more dialogic model, where the perceptions of the non-expert are not  
227 simply misconceptions to be adjusted, but instead become concerns to be  
228 addressed through discussion and interaction. The approach allows researchers to  
229 assess not only what participants (both expert and non-expert) involved with an  
230 issue think, but also why they think it (Kiker et al., 2005). This is valuable to ~~both~~  
231 expert and non-expert alike, as it allows both parties to fully express their  
232 perceptions of an issue and come to a greater understanding of the other party's  
233 perspective. The approach therefore allows the refinement of communication to  
234 focus on messages that are salient to both communicator and recipient, which will  
235 increase the efficacy and significance of these communications (Frewer, 2004).

236

237 3 Applying the Mental Models Method

238

239 The mental models approach to risk (Morgan et al., 2002) is a mixed method  
240 procedure which integrates aspects of Johnson-Laird's Mental Models theory (1983)  
241 with risk communication practice (Morgan et al., 2002). It assumes that the heuristics  
242 ~~and biases~~ used by non-experts to interpret controversial, critical or unfamiliar issues  
243 do not form an entire model that directly reflects the world as the participant  
244 experiences it, but rather constitute a series of interconnecting ideas that may colour  
245 the perception of an issue (Morgan et al., 2002). This qualitative and quantitative  
246 process consists of three main stages:

247

- 248 | 1. Qualitative semi-structured interviews are conducted one-on-one with a broad  
249 sample of the target population, as well as with technical experts in the field  
250 under question. These semi-structured interviews provide the participant with  
251 an opportunity to speak freely about the issue using their own terms or  
252 analogies, which can be examined in detail later, but also to discuss related or  
253 perhaps peripheral topics that the participant feels is relevant (Mabon et al.,  
254 2014). Once this stage is completed, a series of models are constructed  
255 which reflect the key perceptions held by each group and considers how  
256 these perceptions compare across groups of different 'expertise'.
- 257 | 2. A single Qquantitative questionnaires ~~are is~~ constructed from the combined  
258 expert and non-expert models produced after the interview stage. ~~These~~This  
259 questionnaires tests whether the dominant perceptions that are highlighted by  
260 the model ~~as-correctly~~ representing the areas of greatest concern or interest  
261 ~~for-that were expressed by~~ the participants ~~and researcher~~. The statements or  
262 questions are constructed using the language of the non-expert participants  
263 so as to minimise bias. The results of the questionnaire are then compared to  
264 the original models to test their validity in a larger sample.
- 265 | 3. If the model provides a good reflection-fit of the dominant perceptions of the  
266 target population, then a communication is designed that dovetails with the  
267 model content, in order to stimulate useful dialogue or provide information.  
268 This communication is tested for its ability to improve knowledge and  
269 understanding in the target population.

270

271 Whilst it is not unusual for users of the mental model approach to supplement their  
272 interviews with photos or drawings (Vosniadou and Brewer, 1992), two-dimensional  
273 images are not always a suitable inclusion when researching geoscience  
274 conceptions, as they rely on the participant employing a highly developed sense of  
275 spatial reasoning that some individuals struggle to use (Kastens and Ishikawa,  
276 2006). Because geology is a very descriptive and visual science (Frodeman, 1995),  
277 this can lead to misinterpretation of ideas from both the expert and the non-expert.  
278 To address this issue, some previous studies of geological risk have employed 3D  
279 participatory modelling to provide an alternate method of elicitation during focus  
280 groups or interviews (Cadag and Gaillard, 2012). The inclusion of the 3D model  
281 provided participants with a means to test their verbally expressed concepts in an  
282 alternative format. In this study, Morgan et al's (2002) approach was combined with  
283 a three dimensional (3D) participatory model during the semi-structured interview  
284 stage. The use of a 3D participatory component, whereby participants either use or  
285 create a 3D model in the elicitation process, reflects the recognition that often  
286 participants in an interview may have difficulty expressing their thoughts verbally ~~in~~  
287 ~~an interview~~ (Cooke and McDonald, 1986; Ongena and Dijkstra, 2007). ~~(Kastens and~~  
288 ~~Ishikawa, 2006) Because geology is a very descriptive and visual science~~  
289 ~~(Frodeman, 1995), this can lead to misinterpretation of ideas from both the expert~~  
290 ~~and the non-expert. To address this issue, previous studies of geological risk have~~  
291 ~~employed 3D participatory modelling to provide an alternate method of elicitation~~  
292 ~~during focus groups or interviews~~ (Cadag and Gaillard, 2012). ~~The inclusion of the~~  
293 ~~3D model provided participants with a means to test their verbally expressed~~  
294 ~~concepts in an alternative format.~~

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#### 297 4 Details of present research and research questions

298  
299 This study presented in this paper represents a part of broader research into what  
300 perceptions people hold about the geological subsurface. This research examined  
301 common ideas and attitudes to the subsurface with reference to how experts and  
302 non-experts conceptualise the geological subsurface. In particular, questions were  
303 addressed that included: conceptualisation of the structure of the subsurface

304 environment, the impact of human activity, and the influence of natural forces or  
305 phenomena.  
306 ~~This broader study covered all aspects of a society's interactions with geology~~  
307 ~~including: industry, heritage, and recreation.~~ The present analysis focuseds on a  
308 subset of issues particularly relevant to hydrological interactions with the subsurface  
309 environment and the hazards that this might influence. Hydrological interactions with  
310 the subsurface were chosen as they were an unexpectedly ubiquitous theme  
311 identified in the non-expert interviews. ~~This research examined common ideas and~~  
312 ~~attitudes to the subsurface with reference to how experts and non-experts~~  
313 ~~conceptualise the geological subsurface. In particular, questions were addressed~~  
314 ~~that included: conceptualisation of the structure of the subsurface environment, the~~  
315 ~~impact of human activity, and the influence of natural forces or phenomena.~~

316  
317 A combination of participatory, qualitative and quantitative methods was used. The  
318 3D model comprised a 1m x 1m x 1-m sized whiteboard cube, on the top surface of  
319 which was a topographically-moulded aerial photo of each study location, an  
320 example of which is shown in Figure 3. The aim was to enable participants to visually  
321 represent those concepts that related to the subsurface environment in their  
322 immediate vicinity~~area~~.

323 Interviews were conducted by the primary researcher (H.G.) - a geologist with  
324 practical experience working as a formal and non-formal science communicator in a  
325 museum and national park. Care was taken by the researcher to limit bias during the  
326 interviews and a conversational protocol (a relaxed back-and-forth conversational  
327 style) was employed during the interviews (Ongena and Dijkstra, 2007).

328  
329 Figure 3. A blank 3D participatory model used by both expert and non-expert  
330 participants during the semi-structured interviews to assist with non-verbal elicitation.

331  
332 Three locations were selected for the purposes of the survey: one village in Cornwall  
333 and two villages in Devon. These villages had similar demographics - as assessed  
334 using the 2011 census data (Office of National Statistics, 2011) - but different  
335 exposures to geology. The first village, Carharrack in Cornwall (population 1324),  
336 has a strong cultural and historical association with geology (abandoned former tin  
337 and copper mining), but little current geoscience activity in the immediate proximity.

338 The second village, Sparkwell (including Hemerdon) in Devon (population 1246), has  
339 a moderate cultural and historical association with geology, but has a prominent  
340 current geological industry active in the immediate vicinity (tungsten mine and  
341 aggregate quarries). The third village, Chulmleigh in Devon (population 1308), has  
342 neither a strong cultural and historical association, nor a current geological presence;  
343 indeed the local geology is not particularly visible in the landscape.

344  
345 The study incorporated both expert and non-expert interviews. Six interviews with  
346 experts (individuals with considerable experience either in the academic or industrial  
347 side of geology local to the area under survey) were conducted as well as a literature  
348 review of data relevant to a non-expert's understanding of the subsurface. After initial  
349 contact with parish councils was made to establish local awareness of the study and  
350 paper adverts were placed in prominent locations around each village. Non-expert  
351 participants were selected using a 'snowball' method (Forrester, 2010) ~~after initial~~  
352 ~~contact with parish councils was made to establish local awareness of the study and~~  
353 ~~paper adverts were placed in prominent locations around each village.~~ The 'snowball  
354 method' of sampling occurs when you make contact with one or more members of  
355 your target population and ask them to introduce you to others who would potentially  
356 be interested in participating. It is a useful technique for reaching ambivalent or hard-  
357 to reach audiences (Forrester, 2010).

358  
359 A total of 29 interviews were conducted across the three sites. As is described in the  
360 literature (Morgan et al., 2002; Mayer and Bruine de Bruin, 2014), the semi-structured  
361 interview questions were designed after an intensive literature review of the subject  
362 and supplemented by details from the expert interviews. The interviews were audio  
363 recorded and transcribed to ensure that the language of the participant was captured  
364 accurately. Interviews continued until a broad sample was achieved and repetition of  
365 concepts between participants occurred (Morgan et al., 2002). In line with the ethical  
366 approval granted by the University of Plymouth Science and Technology Ethical  
367 Committee, the names of all participants have been anonymised and replaced with  
368 fictitious names as is demonstrated in the results section. The interviews were  
369 conducted between January and September 2014. The questionnaire was designed  
370 after data collection and analysis of the interviews was completed and was  
371 constructed using the data gathered from the semi-structured interviews. The



372 questionnaire was then distributed by post to all households (5214) in the target  
373 areas during September 2015 and was also made available online in the form of a  
374 link to the survey included with all postal surveys, with a total response rate of 228  
375 (4.37%) both online and through the mail. During the time of the initial interviews  
376 (January – March 2014) the UK was experiencing unusually severe winter storms  
377 that resulted in flood damage to key infrastructure across the southwest (e.g.  
378 disruption of main Devon-Cornwall rail line at Dawlish), extensive flooding and some  
379 loss of life. Tand this high-profile flooding may have influenced the content of the  
380 interviews, especially those conducted between January and March 2014.

381

## 382 5 Results: Perceptions of the subsurface, water and geological hazards from 3D 383 drawings

384

385 Participant responses to the semi-structured interviews were diverse and  
386 represented a wide range of opinions and perceptions. Although detailed mental  
387 modelling of the full set of responses is ongoing, an analysis of a subsection of the  
388 results allows some provisional observations to be made.

389

390 The main attention of the study was focussed on the geological subsurface, so first  
391 this paper will provide context with some generalised results about the subsurface  
392 using the data collected with the 3D participatory models. These models provided an  
393 insight into how people visualise the subsurface environment in their area, and in  
394 combination with the verbal results, provide an interesting idea of the perceptions of  
395 the subsurface the people in these three villages hold.

396

397 As experts and non-experts participated in interviews with the same structure and  
398 substance, their results can be directly contrasted to highlight similarities and  
399 differences. The images in Fig. 34 demonstrate some of the key concepts  
400 demonstrated by participants.

401

402

403 *Figure 34: Images of 3D participatory models completed by expert and non-expert*  
404 *participants. a) Eric – an expert participant, represents the expert model, with a*  
405 *logical diagram utilizing more than one side of the model (including the surface), with*

406 detail provided by numerical and factual annotation. b) Edward – an expert  
407 participant, also demonstrates an expert model, with a representation of a fault  
408 structure displayed at the surface and symbols used to identify different rock types.  
409 c) Kimberley – a non-expert participant from Carharrack, conceives the subsurface in  
410 a couple of interesting ways. Firstly, the red shading is used to depict the Earth's  
411 core, initially as a semi-circular shape and then later modified to match the linear  
412 appearance of the rest of the diagram. In addition, the diagram shows some  
413 uncertainty about the inferred ground level, which is drawn with a green zigzag line,  
414 below the actual surface of the model. d) Katie – a non-expert participant from  
415 Carharrack, presents a much sparser diagram, with subterranean buildings  
416 emphasizing the human interaction with subsurface space. e) Charlotte – a non-  
417 expert participant from Chulmleigh, drew a direct link between the surface and the  
418 subsurface in the form of a channel that connects the topographic low (where the  
419 river is shown on the aerial photograph) and an underground body of water, which  
420 cuts across the entire model. Finally, f) Charles – a non-expert participant from  
421 Chulmleigh shows another model which has been interpreted to represent a more  
422 scientific model, with the Earth's core represented at the bottom and the different  
423 layers as being approximations of different scales of geological concepts, from  
424 tectonic plates to erosional surfaces of sandstone.

425

### 426 **5.1 General perceptions of the subsurface from 3D model verbal explanations**

427 One of the initial observations was in the application of 3D spatial reasoning by the  
428 [geoscience](#) experts. This is clearly visible in Fig. 34a and Fig. 34b, where both Eric  
429 and Edward utilised more than one side of the model in association, as well as  
430 making reference to the surface image for contextual cues. The use of 3D spatial  
431 reasoning was common throughout the expert interviews, as this comment from  
432 Ethan indicates:

433

434 ...so as you go down this could be all killas<sup>1</sup>, and could be cut off  
435 by...by... you've got lots of joints, so you have footwalls and hanging  
436 wall and slip planes. So you could find that down here, the further you  
437 go away from the hill, you find the granite's further away?

---

<sup>1</sup> A regional term for Devonian-Carboniferous low grade phyllite (Kearey, 1996)

438 Ethan, ~~commercial and~~  
439 ~~academiegeoscience~~ expert

440  
441 This description includes an inherent use of 3D spatial reasoning, demonstrated by  
442 Ethan in his inference of a change in location of the granite relative to the hill as  
443 influenced by the joints and slip planes. In general it was clear from the way that the  
444 experts used the block models that they were using 3D spatial reasoning. There was a  
445 deliberate connection made between the adjacent ~~walls-sides~~ of the model cube, and  
446 also with the surface topography and the aerial photograph. The experts completed  
447 the models with a great deal of gestural explanation (Kastens et al., 2008), even to the  
448 extent of using the pens provided for annotation to demonstrate a fault structure  
449 present in the area (visible in Fig. ~~34~~b). This 3D spatial reasoning was not, however,  
450 present to the same degree in the non-expert participants. Some spatial reasoning  
451 was used, but it was most often utilised in a purely geographic two dimensional way.  
452 Moreover, all of the non-experts limited their elicitation to a single side of the model  
453 cube.

454  
455 I'm surprised really that ~~that~~ [the quarry] is in a quite high part  
456 compared with others. As you move down here ~~[from the mine site]~~, I  
457 know from my own experience, as you come south ~~from here, the fall~~  
458 ~~of the land is down here and ...~~ the rocks are actually a bit softer ~~from~~  
459 ~~my experience~~.

460 Henry, Hemerdon and Sparkwell  
461 ~~resident~~

462  
463 The models also demonstrated another consistent difference between the experts  
464 and the non-experts, and that was an anthropocentric, or human focussed view of  
465 the subsurface (Slovic, 2010). ~~Whereas, for the expert participants, geological~~  
466 ~~activity was considered a product of the local geology, for many non-expert~~  
467 ~~participants, human interaction with the subsurface was the only important factor~~ ~~For~~  
468 ~~the expert participants, a concept of the geology came first, which stimulated~~  
469 ~~concepts related to the mining, however, for the non-experts it appeared that the~~  
470 ~~mining, (or other types of human interaction) was a concept that came first and only~~  
471 ~~provided an indicator to the geology subsequent to that human interaction~~. This

472 | anthropocentric perspective of the subsurface is demonstrated in Fig. 34d, which  
473 | also indicates how some participants who held a strongly anthropocentric model had  
474 | a great deal of difficulty in adding any other detail to their expressed perception of  
475 | the subsurface.

476

477 | Q: So, if you were to, like, dig straight down now, what would you  
478 | come across?

479 | A: I don't know. I don't want to know.....There could be things  
480 | underneath the ground like that kind of thing.... Other houses, I don't  
481 | know.

482

Katie, Carharrack

483

resident

484

485 | Perceptions shaped around human concerns contrast with the more expected  
486 | conventional geological depiction of subsurface relations (e.g. Fig. 34c). These types  
487 | of diagram (called 'scientific' from here on) varied in the level of detail provided, with  
488 | some (Fig. 34ce) being very detailed, and exhibiting a large amount of additional  
489 | annotation relating to dates and eras, both historical and geological. These non-  
490 | expert scientific models focus attention on a range of themes. Some participants, for  
491 | example as shown in Fig. 34c and Fig. 34f, focus very strongly on the centre of the  
492 | Earth. In Fig. 34f the focus was more specifically related to the types of layers one  
493 | might encounter if penetrating the subsurface, but also included a visual link to the  
494 | Earth's core, which was identified early in the construction of the diagram. The role  
495 | and importance of underground water was also indicated in the way that participants  
496 | depicted the subsurface, such as with rounded pebbles.

497

498 | A key point emerging from the semi-structured interviews was a strong  
499 | disassociation among non-experts between the subsurface and the surface  
500 | environment in ~~non-experts~~. This is most evident in Fig. 34c, where despite the  
501 | surface-top of the cube being a representation of the topography ~~ie-surface~~, and the  
502 | respondent being asked to present what she thought was 'directly beneath her', an  
503 | artificial ground surface was added to the side of the cube. This disconnection was  
504 | demonstrated in multiple model depictions and, alongside the limited use of 3D  
505 | spatial reasoning, is a strong discriminator between the non-experts and the experts.

506

507 When a connection between the surface and subsurface was presented by non-  
508 experts it was frequently vague and portrayed in a general sense that was more  
509 related to the nature of the rock in the area, as is evident in the following quote:

510

511 But granite, I would have thought, just about everywhere, really. I  
512 don't know what depth that would be. It's probably near the surface  
513 but I would have thought there would be granite around.

514 Katrina, Carharrack

515 resident

516

517 In this example, the existence of a particular rock type was not consciously linked with  
518 any visible landscape feature. In contrast, the remarks below highlight an expert  
519 connecting a mapped unit of geology below with a specific landscape feature above,  
520 and using the observable outcrops as cues to discern the underlying differences in  
521 local geology.

522

523 Well perhaps it's not the same sandstone for a start, you can make a  
524 measurement of one sandstone in one hill there and then you know  
525 it's dipping towards the hill, ... ~~er~~ ... towards us, ~~and~~ because that  
526 sandstone is all the same, ~~it could be a completely different~~  
527 ~~sandstone.~~

528 Edgar, geoscience expert

529

## 530 **5.2 Combined mental model**

531 By integrating the findings of experts and non-experts from the three study areas, a  
532 final combined mental model has been obtained (Fig. 45). This model represents a  
533 collective view of the public perception of the geological subsurface, especially  
534 focusing on the interaction between surface and subsurface elements in this  
535 conception. The central feature is the connection between the surface and the  
536 subsurface. Most participants alluded to some degree of linkage, but it was the expert  
537 participants who consistently used this connection in constructing their subsurface  
538 model. This difference between the experts and the non-experts was also present in  
539 other shared nodes, such as 'layers' and the 'soil-rock boundary', but of particular

540 interest to this study is the emphasis from the non-experts on the nodes of 'water' and  
541 'flooding'.

542

543

544 | *Figure 45. A mental model of expert and non-expert perceptions of the subsurface in*  
545 *the southwest of England. Rectangular nodes are those shared between experts and*  
546 *non-experts, oval nodes are those expressed by non-experts alone. The three*  
547 *frames '3D thinking', 'scale' and 'technical and local terms' have been placed*  
548 *externally as they provide context for all of the other nodes.*

549

## 550 6 Detailed analysis of themes relevant to Hydrology and Hazard

551

552 To explore the usefulness of this model for applied geoscience in general and  
553 geohazards in particular, this section examines in more detail the two non-expert  
554 nodes [in Figure 5](#), 'water' and 'flooding'. These nodes potentially offer an interesting  
555 insight into the general perceptions of the non-experts into the geological  
556 subsurface. ~~Both relevant data from the 3D participatory approach and the larger~~  
557 ~~survey will be reported here.~~

558

559

### 560 **6.1 Underground rivers.**

561 Firstly, although water was mentioned by the expert participants, it was very much a  
562 peripheral concept, ~~more closely related~~[as is shown in this refernece](#) to mining  
563 activities ~~and industry.~~

564

565 We'll have to satisfy the Mines Inspectorate that what we are doing is  
566 safe and won't result in potential mine flooding. So ...~~er...~~I don't  
567 know, I suspect that the ...~~er...~~ presence of those mine workings  
568 would be a nuisance if we drilled into them so we have to avoid them  
569 from that point of view, but potentially represent quite a good...

570 ~~er...~~water source for us.

571

Eric, ~~commercial~~

572 ~~geology~~[geoscience](#) expert

573

574 For the non-experts, however, the presence and movement of water was frequently  
575 mentioned, most prominently in the recurring notion of underground rivers.

576

577 I think you'd find a lot of water and I imagine there would be lots of  
578 channels. Cos I think the water would have to seep into the ground  
579 and it has to run down cos we are so high that I think there would be  
580 an underground network of holes or natural sewers-...

581 Just because of the pure volume of water that we have and we don't  
582 flood as much so there might be some kind of water table that bits of  
583 land, kind of, not floating on top but almost like resting on top.

584 Christian, Chulmleigh

585 resident

586

587 I think water, if you go down, there's... you know... water would  
588 come off of different bits, different directions and little bits, a bit like  
589 underground streams really, but then finally I think you'd get these  
590 solid stones where there's nothing there really.

591 Charlotte, Chulmleigh

592 resident

593

594 Well, I think water, you know, the amount of rain that we've had you  
595 know, over the last couple of years especially, it's not better for this  
596 area... [Laughter] ...because it gets into these tunnels sometimes I  
597 think and then it...just got nowhere to go.

598 Kim, Carharrack

599 resident

600

601 So I imagine that the top... the top sort of surface... would be 15  
602 feet, and then you would get into a granite and that would be... I  
603 don't know how far down then. That would go on down and I imagine  
604 that in that there are waterways and underground streams and that  
605 sort of thing... gGoing through the granite.

606 Howard, Hemerdon and Sparkwell

607 resident

608

609 | The perception of the existence of underground rivers as the principal pathway for  
610 | water to move in the geological subsurface was so common that one of the  
611 | questions in the subsequent questionnaire was dedicated to it. Questionnaire  
612 | recipients were asked how much they agree with the statement: 'Water naturally  
613 | forms channels underground in order to flow through rock'. The majority of  
614 | respondents (78.9%) chose to either agree or strongly agree (Fig. 56.), showing how  
615 | prevalent this perception was amongst the questionnaire sample population.

616

617

618 | *Figure 56. Attitudes of questionnaire respondents (n=223) to the statement 'Water*  
619 | *naturally forms channels underground in order to flow through rock'.*

620

621 | This misconception of subsurface water routeways also appeared to relate to the  
622 | permeability of water through different rock types. Some types of rock seemed to be  
623 | perceived as allowing water to pass through them more easily, but other types of  
624 | material such as clay were more of a barrier.

625

626 | But, a lot of it must be broken killas underneath because it - water -  
627 | literally drains, disappears. You don't get waterlogged ground  
628 | generally in this area, you know.

629 | Kenneth, Carharrack

630 | resident

631

632 | So there is water under us here which I suppose has been formed or  
633 | collected in certain layers - or runs through certain geological layers,  
634 | but right under this house - or under Chulmleigh, I couldn't tell  
635 | whether we were built on rock or what sort of strata, to be honest.  
636 | There's a lot of stone, I wouldn't have thought it's granite but it could  
637 | be.

638 | Christopher, Chulmleigh

639 | resident

640

641 | **6.2 Water moving through rocks.**



642 Some participants also attempted to explain how water does move through rocks,  
643 with particularly descriptive techniques.

644

645 I think it filters through the rock. Yeah, I think it does. It comes down  
646 like rain through rock, doesn't it? And as long as they're pumping,  
647 then they've got a dry place to work, but it will come up as it did until  
648 the mine floods. And I think it will flood almost to surface, as far as I  
649 remember.

650 Kara, Carharrack

651 resident

652

653 When this notion of the permeability of rocks was posed in the questionnaire as  
654 'Water cannot flow through solid rock' (Fig. 67), the majority just over half of  
655 respondents answered the question incorrectly, choosing either the wrong answer  
656 (28.6%) or 'I don't know (21.8%)'. Whilst 49.5% answered the question correctly,  
657 agreeing that water could pass through solid rock (although many added an  
658 additional note to the question specifying different types) of rock that would influence  
659 their perception. Just over a fifth of respondents, however, selected the 'don't know'  
660 option (as well as eight participants who left the answer blank), which suggests a  
661 significant level of uncertainty exists in public perception of subsurface hydrology.  
662 This suggests that a large number of participants are uncertain about the properties  
663 of subsurface hydrology.

664

665

666 *Figure 67 Attitudes of questionnaire respondents (n=220) to the statement 'Water*  
667 *cannot flow through solid rock'.*

668

### 669 **6.3 Water and instability.**

670 Another common concern expressed by participants was that presence of water in  
671 the subsurface would result in instability and possibly cause ground failure or  
672 collapse. This notion was expressed differently in the different locations. In  
673 Carharrack, for example, the sense of instability was strongly connected to the  
674 historical mining heritage present in the area.

675

676 It's a different kettle of fish mind you those sinkholes, but I'm  
677 wondering if a lot of rain is seeping into old mine workings and might  
678 make them sink.

679 Kevin, Carharrack

680 resident

681  
682 In Hemerdon and Sparkwell, in contrast, concern was expressed for the impact of  
683 new mining activity on existing hydrological environments.

684  
685 You can't keep digging up what's underneath you. It alters things. It  
686 alters the landscape. It alters what comes out of the ground. It alters  
687 the water table.

688 Hannah, Hemerdon and Sparkwell

689 resident

690  
691 ~~Finally, in Chulmleigh instability was expressed in relation to erosion — particularly of~~  
692 ~~arable land — which was often also connected to flooding.~~

693  
694 ~~We were on the point where the river comes right through and we~~  
695 ~~noticed that the river was taking away part of our land so I called in~~  
696 ~~somebody to explain that rivers do that, they change course and~~  
697 ~~lose some and you gain some.... But we didn't get flooded; it wasn't~~  
698 ~~a question of that, just watching my land being washed away and~~  
699 ~~deposited on somebody else's land.~~

700 ~~————— Chester, Chulmleigh~~

701  
702 For the experts, this connection between geology and flooding had been a fairly  
703 logical one, but, in general, non-expert participants did not consider this issue a  
704 geological link. Instead, most believed that the flooding had a definite-superficial  
705 cause and it was connected to human activity on the floodplains.

706  
707 Q: Can you think of anything you've seen to do with geology in the  
708 news recently?

709 A: No, except...um... and this is a bit broad, the flooding in the  
710 Somerset Levels and that's not...really... to do with that [geology].  
711 Christie, Chulmleigh

712 resident

713  
714 So much of things I think of relate to geography I suppose, whether  
715 it's flooding in Bangladesh or India or China you know so it's more  
716 geography related rather than geology. I'm not sure it contributes.  
717 Heather, Hemerdon and Sparkwell

718 resident

719  
720 I know you have to progress [with new mining development]. To  
721 what end, though? Because you can keep progressing and now look  
722 at us. We're getting all this flooding.

723 Hannah, Hemerdon and Sparkwell

724 resident

725  
726 Although attitudes to flooding and ground instability caused by the presence of water  
727 were not investigated directly, the evidence from the qualitative interviews provides  
728 interesting inferences. The non-expert misconception of underground rivers was not  
729 anticipated at the outset of the research, although it could possibly be expected from  
730 anecdotal experience (Kasperson et al., 1988). Common misconceptions like the  
731 prevalence of underground rivers expose deeper issues, such as the public's  
732 understanding of how water moves through subsurface environment and how water  
733 in the subsurface can impact ground stability (Thomas et al., 2015).

734

#### 735 **6.4 Additional/other themes.**

736 Although this study indicates the conceptual gap that exists between experts and  
737 non-experts in the context of the geological subsurface, particularly subsurface  
738 hydrology. This type of study also provides useful context for communicators. For one  
739 thing, the qualitative interviews themselves show the value that the public place on  
740 gaining new and more detailed information that will allow them to continue to make  
741 effective decisions about our changing environment. This was highlighted by  
742 questions raised by participants in connection to the recent flooding events, which

743 | seemed to show that current events had produced an opportunity for communication  
744 | that wasn't present previously.

745

746 | And actually, I have to say the Somerset levels recently have  
747 | made me think a lot more about the geology and how they flood  
748 | and how we build on floodplains. We're taking no notice of what's  
749 | underneath and whether anything can drain away. So, I think it  
750 | would be much more important to all of us soon.

751 | Kimberley, Carharrack resident

752 | 7 Discussion and Conclusion

753

754 | As well as 'making public' misconceived ideas about how the natural world works,  
755 | mental models can expose non-expert perceptions that are so outlandish that the  
756 | expert might never have considered them. In the following statement, a non-expert  
757 | links news stories he has heard about earthquakes and fracking with resource  
758 | extraction.

759

760 | It does concern me a bit sometimes the number of major  
761 | earthquakes we seem to be getting around the Pacific. I'm  
762 | wondering why. Is it something we're doing to the world that's  
763 | causing this? I don't think its fracking because they aren't fracking  
764 | there. Maybe because they're taking oil out of the ground and its  
765 | releasing pressure so that the world plates can move about a bit  
766 | more. I don't know.

767 | Hugh, Hemerdon and Sparkwell

768 | resident

769

770

771 | 7 Conclusion

772

773 | Beyond the occasional ability to expose fairly perverse misconceptions about the  
774 | Earth's systems, the mental models approach provides valuable context for  
775 | geoscience communicators. Its main benefit lies in bringing to light alternative  
776 | scenarios that are central to the way some participants' analyse the processes that

777 operate beneath their feet. In this regard, the heightened 'anthropocentric view' is an  
778 important perspective, and one that has been recognised previously. Lave and Lave  
779 (1991), for example, found in a similar study that some participants would orientate  
780 their whole perception of past and future flood events on the fact that they were  
781 'human-made'. Not appreciating the geological aspects of flooding may mean that  
782 people conceive an inaccurate view of local flooding threat (e.g. from rising  
783 groundwater levels).

784  
785 Ordinary people's anthropocentric depiction of the subsurface is likely to have been  
786 overlooked by communicators, ~~certainly because~~ it is not present in the expert  
787 interviews in any noticeable way. It is revealed because the mental models method  
788 establishes direct comparisons of expert and non-expert perceptions on the same  
789 issue. Such inter-comparisons highlight fundamental mismatches of thinking, such  
790 as the use of 3D spatial reasoning and the logical connection between the surface  
791 and the subsurface. They also shed light on the reasoning behind misconceptions,  
792 such as the ubiquitous popular references to underground rivers, and offer up  
793 additional nuanced detail to communicators attempting to grasp the public viewpoint.

794  
795 Through mental models, geoscientists can be armed with empirical, detailed and  
796 generalised data of perceptions surrounding an issue, as well as being aware of  
797 unexpected outliers in perception that they may not have considered relevant but  
798 which nevertheless may locally influence communication. Using this approach,  
799 researchers and communicators can develop information messages that more  
800 directly engage local concerns and create open engagement pathways based on  
801 dialogue, which in turn allow both groups to come together and understand each  
802 other more effectively. Given the ongoing wider challenges in geoscience  
803 communication, especially in contested subsurface interventions associated with  
804 shale gas extraction, carbon capture and storage and radioactive waste disposal, the  
805 ability for geo-communicators to be more carefully attuned to how individuals and  
806 communities think will become ~~ever more severely~~ increasingly tested.

807  
808 Author Contributions  
809 H. Gibson, I. Stewart and S. Pahl designed the survey protocols and interview  
810 questions. H. Gibson conducted all interviews and completed primary analysis and

811 construction of the mental model. A.Stokes and S.Pahl assisted with secondary  
812 analysis of data and construction of mental model. I.Stewart assisted with  
813 construction of the mental model. H.Gibson designed the questionnaire with  
814 assistance from S.Pahl, I.Stewart and A.Stokes. H.Gibson prepared the manuscript  
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816

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823

824

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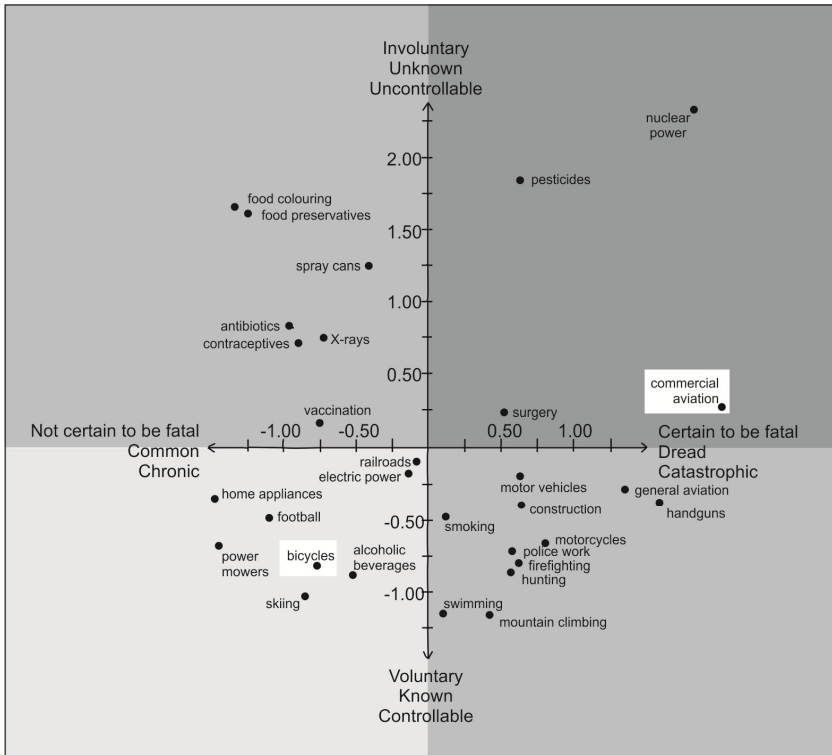
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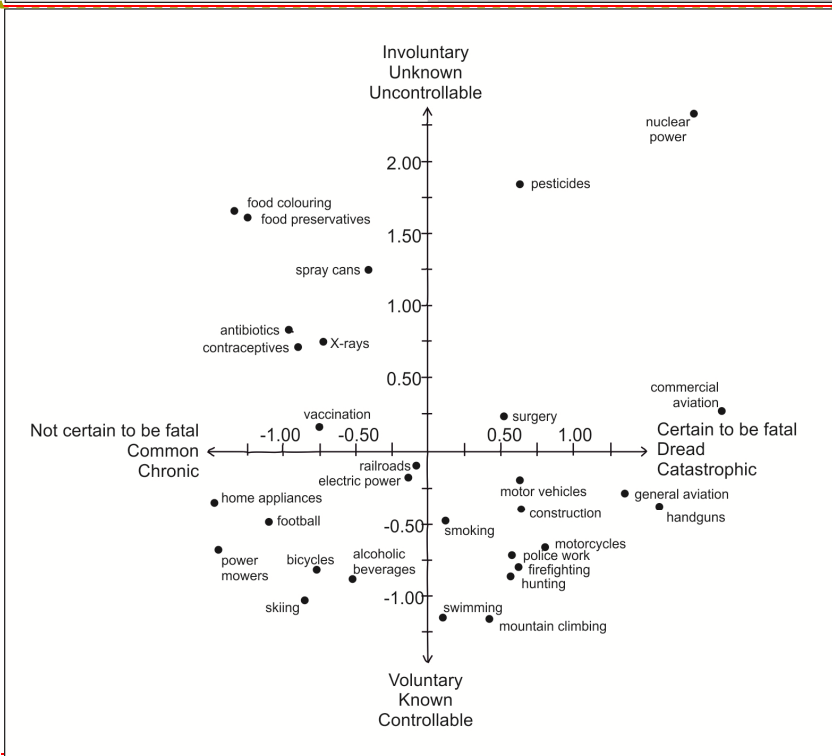
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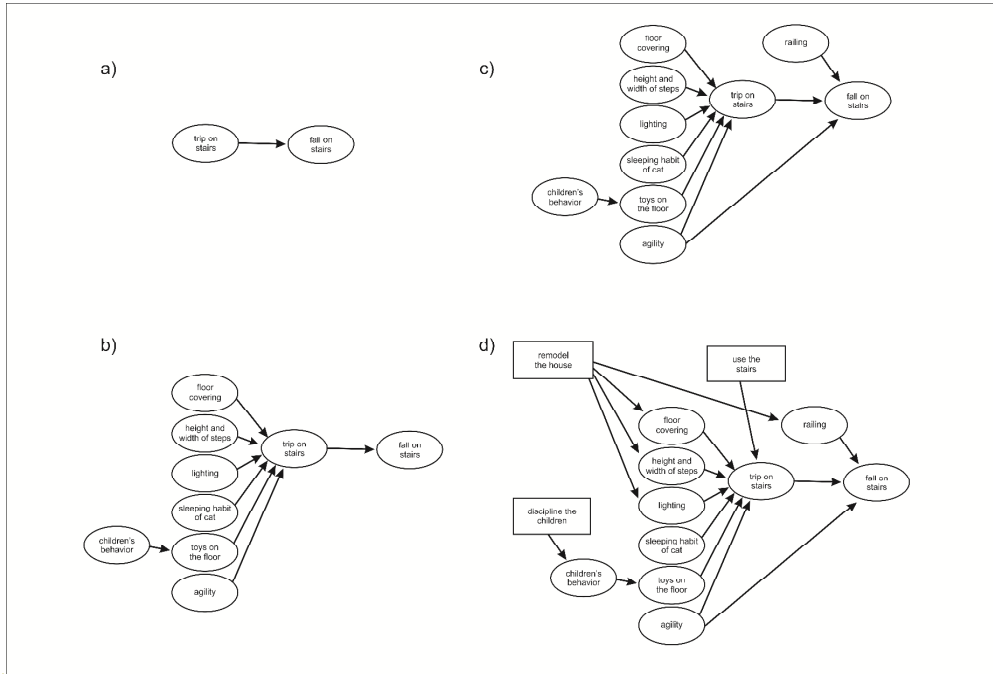
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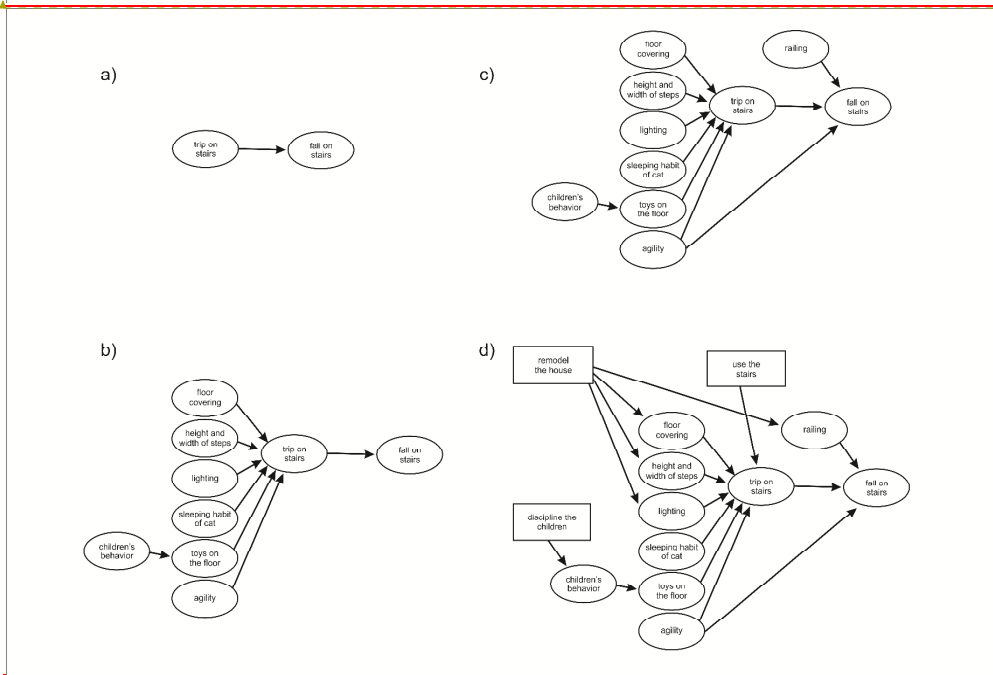
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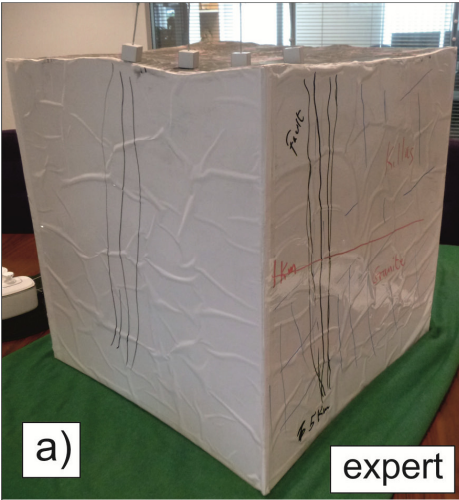
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Figure 3.

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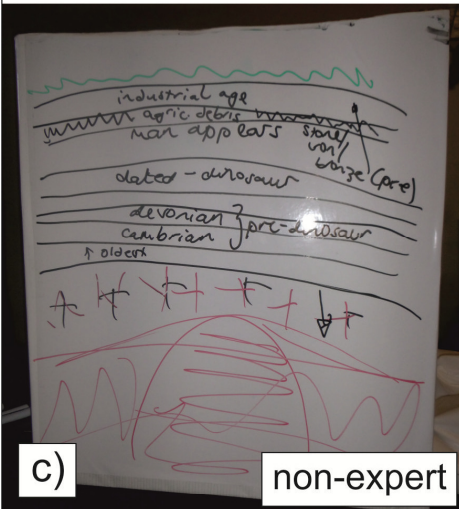
a)

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b)

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c)

non-expert



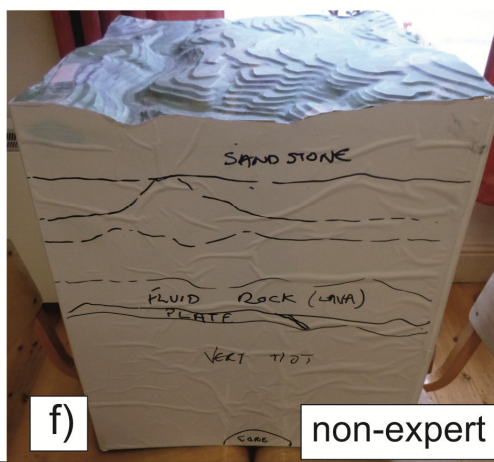
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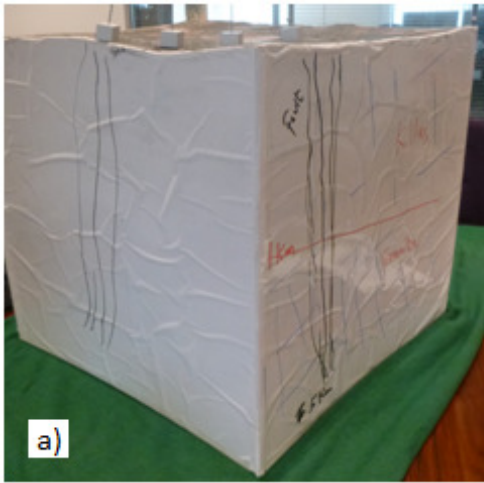
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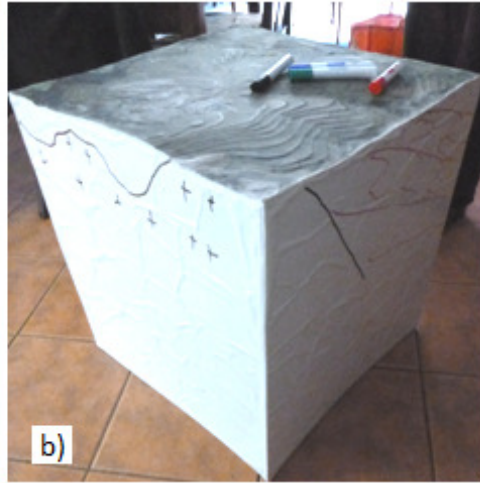


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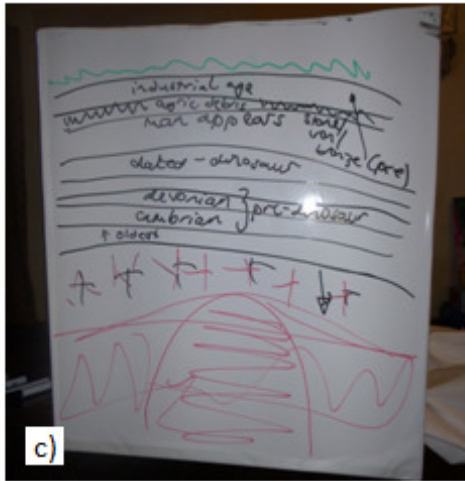
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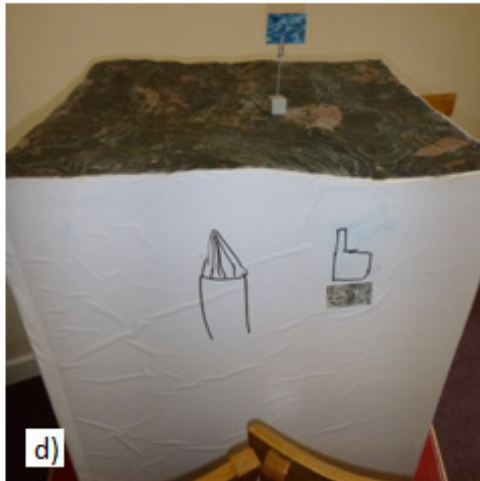
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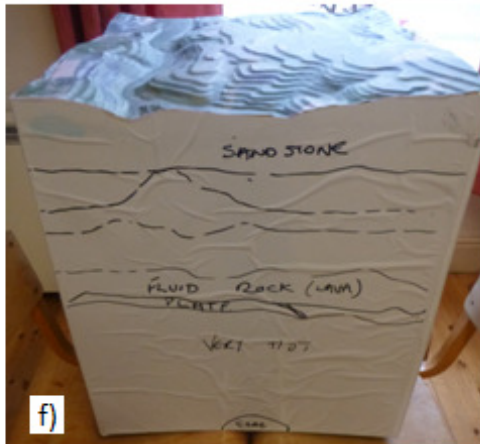
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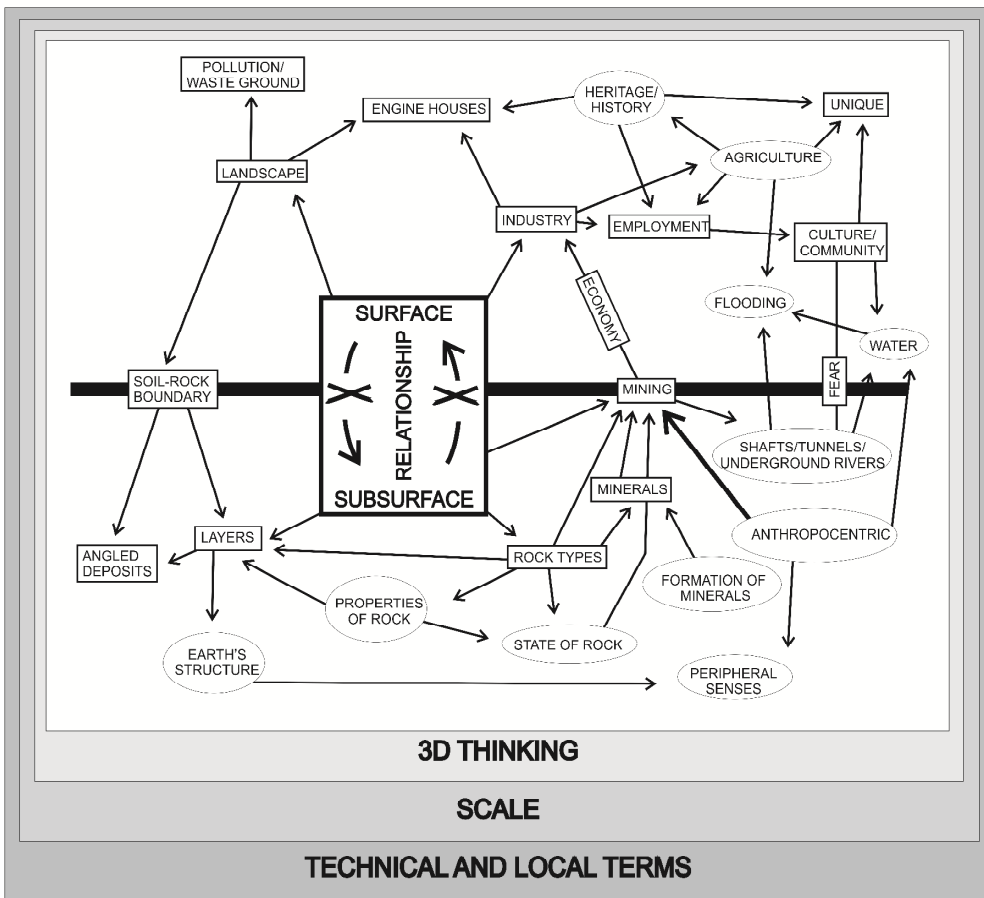
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Figure 34.



952  
 953 | Figure 45.  
 954

'Water naturally forms channels underground in order to flow through rock'



78.9% agree



6.7% disagree



14.3% don't know

955

'Water naturally forms channels underground in order to flow through rock'



78.9% agree



6.7% disagree



14.3% don't know

956

957

958

Figure 56.

'Water cannot flow through solid rock'



28.6% agree



49.5% disagree



21.8% don't know

959

'Water cannot flow through solid rock'



28.6% agree



49.5% disagree



21.8% don't know

960

961

Figure 67.