Communicating with public audiences about the geological subsurface: thinking inside the box.

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Abstract

Community concerns over resource extraction and public anxieties about insertion of waters and waste are creating a growing societal unease about geological exploitation of the subsurface. Addressing these emergent areas of socially contested subsurface geoscience is difficult for many academic and industrial geologists, not least because translating unfamiliar concepts of the geological subsurface between stakeholders presents a challenge. This paper proposes a novel approach to engaging publics with geological issues: the GeoCube. Combining 3D Participatory Mapping with the Mental Models approach, the GeoCube allows participants to explore complex geological ideas. The GeoCube method, developed for a UK study in a Cornish mining village, revealed the ways that experts and non-experts conceptually penetrate the landscape surface to the invisible geological subsurface, highlighting the lack of similarity these two groups demonstrate, allowing communicators to better understand how to bridge the gap.

Introduction

The geological subsurface represents an alien frontier in public consciousness – out of sight and out of mind. Increasingly however, underground geological issues are rising to the surface as long-standing community concerns over conventional resource extraction combine with new public anxieties about insertions of waters and wastes in novel geological technologies to create a growing societal unease about our exploitation of the 'land below ground' (Evans et al., 2009; Stewart & Lewis, 2017). A negative framing of the subsurface interaction by geoscientists, the notion of scientists 'tampering with the subsurface', has been identified as an inhibitor of social acceptance of two such novel geological technologies: Carbon Capture and Storage (CCS) (Tokushige et al., 2007; Corner et al., 2011; Wallquist et al., 2012; Selma et al., 2014) and radioactive waste disposal (Skarlatidou et al., 2012; Wallquist et al., 2012). More generally, securing the social licence to operate from communities faced with geoscience interventions beneath their backyard is becoming an increasingly fraught challenge for many energy and resource developments around the world.

Addressing such emergent areas of socially contested subsurface geoscience is difficult for many academic and industrial geologists, largely because the remote and unfamiliar nature of the subsurface realm presents both acute technical uncertainties and problematic lay misconceptions (Greenberg et al, 2014). In regards to CCS, for example, Wallquist et al. contend that '…many people lack the basic physical and chemical understanding about CO^2 and the natural conditions of the subsurface' (Wallquist et al., 2010, pg 8561). The typical response within the geoscientific community has been to counter such misconceptions through 'better' communications, tempering the technical jargon and conveying underground geological relations through clearer graphical visualisations (Segio et al, 2013). While this tendency to 'educate' the public with information to fill their inferred knowledge deficit endures among many scientists, among communication professionals there has been a shift away from simply conveying 'matters of fact' to engaging people in more complex dialogues over their 'matters of concern' (Stewart and Lewis, 2017; Nisbet and Scheufele

2009, Bucci, 2008, Sturgis and Allum, 2004). In the context of subsurface geoscience, a critical challenge is how ‘experts’ can engage in mutual dialogues with ‘non-experts’ across such an apparent comprehension gap.

In this paper, the results of a comparative study of how experts and non-experts conceptualised the geological subsurface in a mining community in Cornwall, south-west England are presented. The aim of this socio-cognitive research was to better understand how ordinary residents conceptualise the unfamiliar world beneath their feet and, from this, to derive insights that offer geoscience professionals more effective ways to engage with lay publics.

Methodology: an integrated ‘3D Participatory Mapping’ and ‘Mental Models’ approach

To overcome the interconnected issues of unfamiliarity, inaccessibility of the environment, and obscure language, the study combined two discrete approaches: Mental Models and 3D Participatory Mapping.

The Mental Models approach is a widely applied psychological perception assessment tool that uses a mixed qualitative and quantitative methods approach to identify the causal beliefs and perceptions people have about unfamiliar topics (Bostrom et al, 2015). The first stage focuses on qualitative semi-structured interviews with both expert and non-expert participants (Morgan et al, 2002). No matter how irrelevant or disconnected a participant’s observations appear to be to the investigator, the ideas shared during the interviews build into a broad and interconnected cognitive model of basic scaffolding concepts about that topic (Morgan *et al*., 2002). Although expert participants will be fluent in the topic, non-experts need no detailed knowledge to produce a Mental Model and their resulting schemas often reveal unexpected connections that are radically different to conventional expert notions (Goel, 2007; Vari, 2004). Moreover, because expert and non-expert elicitations are considered alongside each other as equally valid (true) representations, the Mental Models approach also helps counter the perceived authority preferentially bestowed to expert judgement, a key concern in effective stakeholder engagement. Although traditionally used in applied psychology, this approach has value in many other disciplines, particularly in geoscience, though to date this method has been limited to a study exploring lay conceptions surrounding radioactive waste disposal (Skarlatidou et al 2012).

Mental Models are often expressed as a visual diagram of participants interconnected concepts, which can include both concrete and abstract ideas, as well as emotions, values and opinions. For the purposes of this research, the authors wanted to explore how to translate this 2D approach to a 3D conceptual environment, reflecting better the spatial context in which geologists normally operate.

Another concern for geoscientists engaging with stakeholders is that because geology is a descriptive and visual science (Frodeman, 1995), novel and complex technical language or concepts can lead to misinterpretation of ideas from both the expert and the non-expert perspectives. For example, in the context of geological risk, interviews and focus groups have revealed that non-expert participants often have difficulty in expressing or verbalising unfamiliar hazard concepts (Cadag and Gaillard, 2012). To overcome this barrier, some risk communicators have adopted a 3D Participatory Mapping approach to gather data from participants, to help collectively represent, visualise and verbalise critical geological concepts and issues (Cadag and Gaillard, 2012; Maceda, 2009). 3D Participatory Mapping has been used successfully to gather perceptions of volcanic hazard and risk from a diverse community in Montserrat in the West Indies and, in general terms, the approach enables the elicitation of complex socio-cultural data combined with pertinent geographical and geological data (Haynes et al, 2008).

3D Participatory Mapping is useful beyond risk communications to allow participants who consider themselves unfamiliar with their geological subsurface, a way to create their own visualisations or maps of the subject in question. It gives these participants a very loose structure to guide their depictions of their local geology, whilst giving them enough freedom to express these ideas in their own way, using drawing, written words, printed images, gesticulation or a combination of these.

In this study, Mental Models (to provide access to unfamiliar concepts and equity in expert and non-expert knowledge) were integrated with with 3D Participatory Mapping (to provide non-verbal clarification of context and interpretation), in order to help elucidate lay conceptualisations of the subsurface. The study was located in the small historic mining community of Carharrack in Cornwall, southwest England (Figure 1) and was based on a series of expert and non-expert semi-structured interviews, including participants' visual depictions of the geology using a 3D model of underground space – the 'GeoCube'.

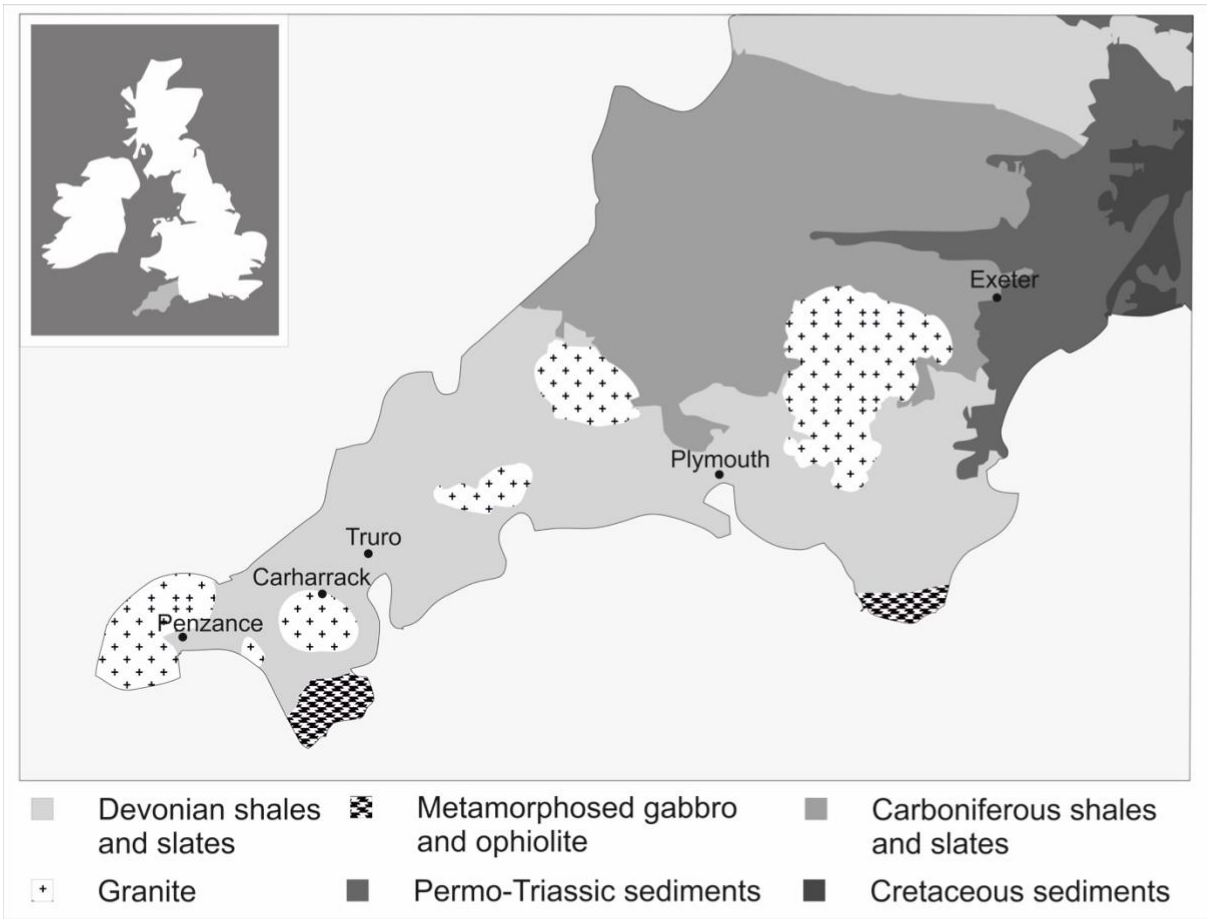

Figure 1: Geology map of the southwest highlighting main geological types and important regional towns.

Constructing the GeoCube

The GeoCube is a simple interactive device for the elicitation of complex and interconnected ideas about the geological subsurface in Cornwall. It comprises a $1m^3$ plastic frame, the top surface of which has a topographic model of the study area ($5km^3$) draped with the associated aerial photo. The four sides of the frame are whiteboards on which participants were invited to represent their concepts textually, visually or using pre-selected images of undefined elements of the subsurface.

The first stage of the study involved semi-structured interviews combined with a 3D Participatory Mapping exercise. Interviewees were selected using a convenience and snowball sampling method (Robinson, 2014) by responding to local advertisement flyers asking for participants for a study on geology. Although this recruitment method could be criticised for introducing bias by encouraging only participants who have pre-existing geological knowledge, in fact several of the participants recruited expressed a lack of familiarity with geology as a topic. Twelve non-expert participants, who met the basic recruitment criteria (over 16 years old and resident within 5 miles of the study village), were recruited along with two expert participants (an individual with either subject relevant degree level education or at least 10 years' experience of working in a geoscientific field).

As an additional check of internal validity, recruitment of interview participants continued until the researcher achieved redundancy (Baxter and Eyles, 1997), where the same major concepts were being repeated and few new ones were being introduced. Each interview was transcribed and coded by theme using the constant comparison method (Kolb, 2012) and the surveys were constructed from the data produced in the interview stage. Once data had been coded it was constructed into the Mental Model by identifying expressed links between concept themes (Morgan et al, 2002). The data was thematically analysed using the constant comparative approach (Glaser, 1965) to identify key themes and important gaps between the expert and non-expert participants conceptualisations of the geological subsurface beneath Carharrack.

For the second stage of the study a questionnaire was posted to all households within the post code for Carharrack (with an optional online link to SurveyMonkey™ to promote accessibility) and were requested to return their responses by a pre-paid envelope. In total, 78 participants returned the survey.

The second stage of the Mental Models approach, only completed by non-experts, was important to externally verify the results of the first stage, by testing the ideas shared on a wider sample of the population. The results of the questionnaire were descriptively analysed to identify to what extent the concepts identified in the first stage of the study were representative of the research population and also compared with expert answers to the questions, to identify a degree of ‘match’. Several questions explicitly examined the relationship between the landscape based surface and the geological subsurface, using both descriptive text-based and graphical forms.

Results: Identifying the gap between the expert and the non-expert

The GeoCube proved to be a useful tool for drawing out the varied conceptions of participants about the geological subsurface. From 14 interviews that generated hundreds of data points, three general tendencies by which the participants conceptualised the relationship between surface and subsurface were revealed (represented by select images in Figure 2).

Figure 2: Four images depicting the Geo-Cube in use. 2a is the blank cube showing the aerial photo laid over a topographically correct model, with white board sides. 2b is an expert model with the stages of elicitation depicted by numbers, 1 being the first, 10 being the last, with a focus on the 3d aspect of the mental model, a connection between surface and subsurface elements and a reliance on appropriate technical language. 2c is the first of two non-expert models, 2c focusing on the geoscience-centric approach that is geologically logical, but not locally relevant, with a very clear gap between the surface and subsurface. 2d is the other non-expert model which is anthropocentric, relying on a use of human

structures to penetrate from the surface to the subsurface, but little detail of the geology surrounding that human structure. Neither expert model depicts a use of 3D spatial reasoning at this stage in the elicitation.

The study reveals a distinct gap between the way that expert geoscientists connect the visible surface with the invisible subsurface, which was not evidenced by the non-expert participants. In fact, many non-experts could only draw on subsurface conceptualisations as either completely abstract and not locally relevant, or by relying fundamentally on human structures (such as mines) in the subsurface.

Figure 2a shows how the multiple faces of the GeoCube permit the expression of ideas in 3D, a concept used easily by the expert participants. Figure 2b demonstrates this 3D spatial reasoning ability as well as showing how the expert makes explicit connections between the surface and subsurface. An example of these connections can be seen in the square blocks placed along the top of the model (point 1), which directly correlate to a fault zone depicted on two vertical sides of the GeoCube. This fault zone was identified by the expert by examining surface features to locate it geographically, then extended into the subsurface. This identifies the first tendency of participants, specifically that the experts strongly conceptually connect the surface to the subsurface.

The use of the GeoCube by non-experts, seen in Figure 2c and 2d, revealed a different approach to 3D spatial reasoning than the experts, as none of the non-expert participants used more than one face to depict the geology. In addition to that, the non-expert participant conceptualisation shown in Fig 2c, was not able to connect the visible surface with the subsurface geological environment. An example of this is the false land surface (the jagged green ‘grass’ line indicated by point 17) which demonstrates an abstract and not locally specific approach. The participant also used the GeoCube to indicate a scale not possible on the model (which was constructed to a scale of 5km^3). The example shown in Figure 2c demonstrates the second tendency, which is a reliance by some non-expert participants on abstract or generalised geological concepts, which have little to no local relevance.

The second non-expert diagram (2d) has more of a connection with the surface, but only in a limited way, specifically linking the human interaction with the subsurface. In Figure 2d it can clearly be seen that the participant has drawn a mine structure, and that while the participant provided a great deal of detail about the mine itself, when asked what it would be like around the mine the participant has responded with “dark” (point 7). Although the conceptualisation does link directly to the surface with the geographical location of a similar mine, the connection relies on human rather than natural features, and though that human interaction is very detailed and locally specific, there is no additional link for the surrounding geology. This example shows the third tendency in the data, which was the way that some non-expert participants used human structures to navigate from the surface to the subsurface environment.

The illustrative examples shown here are consistent with general themes relating to the nature of connection between the surface and the subsurface, with non-expert participants using either a geologically familiar, but generic, approach (Fig 2c) or the locally specific, but human centric approach (Fig 2d). Content analysis of the other interviews (n=14) provided additional detail on these gaps, identified between the expert and non-expert approaches to conceptualising the subsurface. These data were then corroborated with the results from the questionnaire survey (Fig 3).

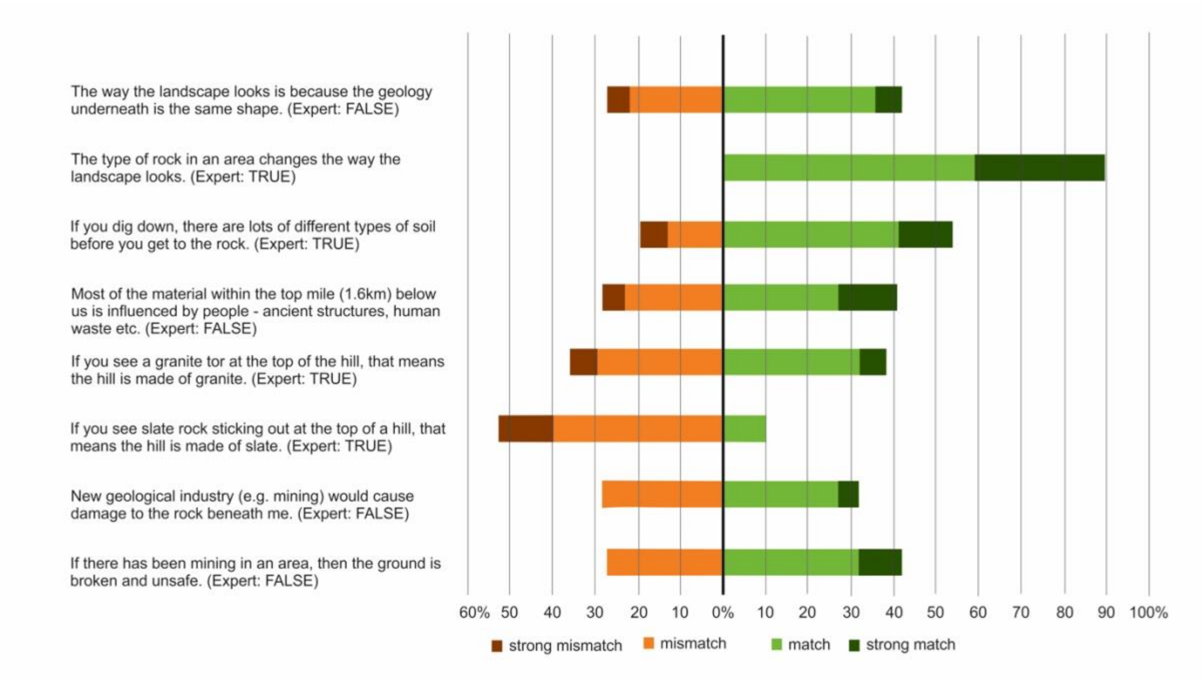

Figure 3: a graph showing the degree of expert match in answers given to a series of questions posed in the follow up to the interview phase of the mental models process. The survey answers show the degree of strength to which the non-expert participants gave the same answers that an expert would in answer to those specific questions (in other words, the degree of match), relating to the relationship between the surface and the subsurface. Additionally a reasonable degree of uncertainty can be seen in the participant responses. In

some questions less than 60% (n= 47) of participants were willing to give a positive or negative answer.

Overall the results of the questionnaire show a reasonably good degree of ‘match’ between the non-experts and the experts. However, in terms of the surface-subsurface conceptual relationship, data shows that certain aspects of the connection (or lack thereof) between the surface and subsurface are better recognised than others. Support for the argument that non-experts imagine more of a disconnect between the visible surface landscape and the invisible geological subsurface than experts, emerges specifically from the responses to the questions relating a seen landscape artefact (granite tor, slate rock) and its correlation with the geology of the immediate subsurface (as seen in Figure 3).

Also apparent is a difference in how non-experts’ view the significance of whether rock visible at the surface is granite or slate. The relationship between slate observed at the surface and slate geology immediately beneath it, is weak, with only 10.3% (n=8) participants providing an expert match answer. However, the relationship between an observed granite tor at the surface and granite geology immediately beneath is more aligned with the expert answer, with 38.5% (n=30) choosing an expert match answer. This is still not the ‘obvious connection’ that most geology specialists would intuitively consider it to be.

It is clear from these data that the approach taken by experts and non-experts to bridge the gap between the visible surface and the invisible subsurface is different. By examining the key features of this difference through the lens of the GeoCube approach, it is possible to identify key areas where geoscientists can reach across the divide between expert and non-expert conceptualisations.

Conclusion

The GeoCube is an innovative approach to contrasting expert and non-expert conceptualisations of the geological subsurface. It has proven itself an instructive method to examine perceptions of a typical population in Cornwall concerning the degree to which surface landscape features are reflected in subsurface geology. This contextual study has highlighted three key general tendencies of those conceptualisations.

1. Expert conceptualisations had a strong connection between visual, surface, landscape elements and non-visible, subsurface, geological elements. Their interpretations also showed a persistent use of 3D spatial reasoning.
2. Non-expert conceptualisations did not have a strong connection between surface and subsurface elements, constructing a recognisably geological model of the subsurface, but one in which there was often little local relevance or salience. Evidence of 3D spatial reasoning was absent.
3. Non-expert conceptualisations did not have a strong connection between surface and subsurface elements, but were able to connect the surface to the subsurface using human interventions, such as mining structures. These models contained

locally specific detail about human impacts and interactions with the subsurface, but little to no geological detail. Some spatial reasoning was used, but it was more often geographical than geological.

This study has made use of two research tools, the Mental Models approach and 3D Participatory Mapping, demonstrating the effectiveness in combining these disparate, but complimentary methods into the GeoCube. Not only does the GeoCube provide a fun, engaging and creative space to generate dialogue, but also, more importantly, it is as a scaffold for eliciting public perceptions of the subsurface. This scaffold can provide a framework for communications, highlighting gaps between expert and non-expert conceptualisations. In this way, the GeoCube is a potentially effective device for shifting emphasis in geoscience communication away from expert-led, one direction dissemination and into participatory, multi-directional dialogues.

Author Contributions

H.G. and I.S. co-designed the interview protocols and the questionnaire. H.G. conducted all interviews, analysis and construction of the mental model. I.S. assisted with construction of the mental model. H.G. prepared the manuscript with assistance from I.S..

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