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Abstract: While there is a literature on public and stakeholder engagement in environmental research and scenario development, less attention has been given to the learning processes that take place in these contexts. We present public perceptions of emissions contraction scenarios for the UK city of Manchester and discuss this in terms of learning theory developed by Lev Vygotsky and Jerome Bruner. A key theme of this is the combination of three learning tools of use in social and individual learning: scaffolding techniques, scenario building and backcasting. We discuss the ways in which our structured scenario-building process, employing Greenhouse Gas Regional Inventory Protocol (GRIP) backcasting software, bring together these components. Following Bruner, learners are treated as scientific reasoners, but with the acknowledgement that there are also important affective and other dimensions to learning.

Highlights

- We reflect on the learning processes of energy scenario participants
- GRIP energy-emissions backcasting software was used with 4 groups of the public
- The process required envisaging strong CO_2 reduction scenarios for a city region
- Key to the theory is Vygotsky’s concept of scaffolding, developed by Bruner

Paper for Technological Forecasting and Social Change

Title: Scaffolding, software and scenarios: applying Bruner's learning theory to energy scenario development with the public

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Abstract

While there is a literature on public and stakeholder engagement in environmental research and scenario development, less attention has been given to the learning processes that take place in these contexts. We present public perceptions of emissions contraction scenarios for the UK city of Manchester and discuss this in terms of learning theory developed by Lev Vygotsky and Jerome Bruner. A key theme of this is the combination of three learning tools of use in social and individual learning: scaffolding techniques, scenario building and backcasting. We discuss the ways in which our structured scenario-building process, employing Greenhouse Gas Regional Inventory Protocol (*GRIP*) backcasting software, bring together these components. Following Bruner, learners are treated as scientific reasoners, but with the acknowledgement that there are also important affective and other dimensions to learning.

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1. Introduction

Research on public attitudes to energy technologies and infrastructure more often than not focuses on single technologies or implementation projects and less commonly explores public attitudes to energy policy, systems or scenarios, in which the interactions and trade-offs among energy options are more apparent. Yet, arguably, public responses to energy options cannot be fully understood without taking into account the wider context in which choices need to be made. A notable illustration of this is the way in which, in recent years, nuclear power has been reframed in terms of its potential contribution to climate change mitigation and energy security [1]. One reason for the limited number of studies of public opinion of energy systems and emissions contraction scenarios may be the lack of tools available to help with the process.

Although quantitative aspects of energy scenarios can be rendered comprehensible to non-specialists, see for example [2], examples of public opinion research with exploratory energy-emissions modelling tools are still uncommon. If we take the UK, for example, there are only two examples in the grey literature, notably an Office of Science and Technology (OST) Science Wise initiative in public dialogue [3]; and research conducted for the UK Research Councils [4]. In the academic literature, only one other UK research project has focussed on the public's views of energy system transformation as a whole [5]. The latter uses the energy-emissions calculator available on the UK Department for Energy and Climate Change website[1], designed for the lay-user, and which has some commonalities with the GRIP software [6], [7] used here.

In terms of reasons why efforts might be made to engage an under-informed public in energy planning or wider scientific activity, rationales fall into three camps: normative rationales view engagement as ethically justified, often on democratic grounds; substantive rationales view engagement as leading to better decisions, often where scientific uncertainty is high, echoing thinking on post-normal science [8]; and instrumental rationales tend to relate to (typically unstated) aims, such as the legitimisation of prior decisions [9] and [10]. To these can be added the public understanding of science rationales of debunking misperceptions, raising awareness and educating [11]; in addition, in a research context and outside of policy processes, engagement may provide opinion-related information for its own sake and for the purpose of furthering knowledge.

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[1] http://my2050.decc.gov.uk/

The suite of scenario studies described below involve an element of all of these rationales, though the focus here is on the potential of participative scenario development to inform the participants, facilitate learning and ultimately lead to behavioural change. Here we reflect on the use of energy-emissions software in scenario generation exercises with groups of the public who are not energy modellers. The output generated by participants as they discussed and decided on energy technology and behavioural options, together with the processes that they are led through, are used as a basis for reflecting on generically-applicable implications for learning principles in public engagement research. For this purpose we draw in particular on three tools: (i) scaffolding and the associated work of Jerome Bruner [12] and [13], who in turn drew on work by Lev Vygotsky from the early 20th century; (ii) scenario-building and in particular Chermack and Swanson's work on learning in scenario contexts [14]; and (iii) Robinson's work on backcasting [15].

In general there is a limited amount of work on learning in scenario contexts. For example, Chermack and Swanson [14] emphasise the role of scenario generation in fostering learning, which in turn is seen as driving individuals and organizations to re-perceive their environments and hence their options for action. Yet, as Chermack observes [16], despite scenario planning being used for decades, there has been little empirical research "to refute, support, or explain the effectiveness of the process": much of the work that does exist on scenario processes is descriptive rather than an attempt to establish correlation or causation between process and consequence [17]. Moreover, while Chermack and Swanson discuss the role of scenario generation in the context of *organisational* learning, as an action-oriented attempt to bring about changes in assumptions and expectations of the future [14], here we focus on individual and collective learning in an experimental and exploratory context. Our aim at this stage is to illustrate the way in which particular concepts from learning theory may help to explain the way in which non-experts are able to engage with unfamiliar technical subjects. Our qualitative and quantitative evidence is used inductively, to support discussion and reveal directions for further work, rather than in an hypothesis testing mode.

The particular software tool and scenario process that we have used, the Greenhouse gas Regional Inventory Protocol (*GRIP*), has been applied in 12 European countries and in California with energy stakeholders, nearly all of whom unaccustomed to energy and emissions modelling [7]. Our thesis is that Bruner's work offers a starting point for understanding aspects of this process, via his emphasis on the importance of the processes of understanding in learning [12], [13]. Specifically, our objectives were to investigate the perceptions of non-energy specialists of particular energy-emissions contraction options in the Greater Manchester city-region. Day-long focus groups were conducted with the public to with the aim of understanding and documenting their perceptions, but also to examine the potential for triggering learning and the potential for behavioural change. We contribute to the existing energy and wider scenarios literature through the use of a computer-assisted combination of three different learning tools: scaffolding, scenarios and backcasting, which aim to enable and facilitate individual and also collective learning. Through its linkage of an expert-designed tool with a public participation process, the paper goes some way to responding to the call to bridge the gap between expert-led and participatory backcasting [18].

Following this introduction, we set out a theoretical framework based on Bruner's pedagogical scaffolding [12], [13], Chermack and Swanson's work on learning through scenarios [14] and Robinson's work on backcasting [15], followed by further detail on the research design and methods employed, findings and discussion. We conclude the paper with suggestions for future research on social and individual learning through energy and other technology scenario building.

2. Bruner and pedagogical scaffolding

Jerome Bruner's thinking over several decades is summarised by Puntambekar and Hübscher [19] and Takaya [20], both of whom take broad perspectives that set Bruner's thinking in the wider contexts of educational practice and thought respectively. Bruner's writing may be said to be primarily focused on the inter-generational transmission and transcendence of culture – on how these processes take place and how they might be facilitated in educational contexts. The processes involved are understood as centring not on exposure to knowledge or information per se - an approach represented at one extreme by rote learning. Nor are they seen as centring on enabling the connection of new information with familiar ideas and contexts, a position put forward by John Dewey [21], [22]. Rather, reacting against the latter, against the 'tabula rasa' model of the mind implicit in behaviourism, and against Piaget's rather rigid developmental stages, Bruner instead proposed that learners construct their own understanding of the world by ordering and categorising information [23], [24], [20]. In short, Bruner's thesis was that the priority for education systems should be the teaching of *how to learn and discover*. This would also allow individuals to transcend the culture into which they were born, enabling them to conceive of new possibilities.

When thinking about how these methods might best be taught, Bruner was strongly influenced by Lev Vygotsky's [24], [25] emphasis on the role of social interaction between teacher and learner in crossing a 'Zone of Proximal Development'. This denoted the distance between an individual's actual and potential level of educational development. Bruner used the term *scaffolding* to describe the process of successful interaction between a tutor and a student in this respect. More recently the term has come to refer to tools that support student learning in project-based and design-based teaching, embracing software tools, curricula and other resources. Commenting on the concept of educational scaffolding, Puntambekar and Hübscher [19] echo the observation of Wood et al [26] that the atheoretical use of the term has become problematic due to the neglect of its original theoretical features, such as ongoing diagnosis of problems, calibrated support and 'fading' of that support, as learners gradually acquire the skills that are being taught. More specifically, Wood, Bruner, and Ross [26] refer to six types of support that an adult may provide: (i) recruiting the student's interest; (ii) reducing the degrees of freedom in a task by simplifying it; (iii) maintaining direction; (iv) highlighting the critical aspects of a task; (v) controlling frustration; and (vi) demonstrating ideal solution paths. Throughout this process, a key theme is a shared understanding of the goal of the activity ('intersubjectivity') [26]. The five criteria for effective scaffolding proposed by Applebee [27] echo these:

- *Student ownership of the learning event*: the instructional task must allow students to make their own contribution to the activity as it evolves;
- *Appropriateness of the instructional task*: tasks should build upon the knowledge and skills that the student already possesses, but should be difficult enough to allow new learning to occur;
- *A structured learning environment:* providing a natural sequence of thought and language, presenting the student with strategies for approaching the task.
- *Shared responsibility: t*asks are solved jointly and collaboratively rather than evaluatively;
- *Transfer of control:* learners gradually take greater responsibility for progress.

Comparing Wood, Bruner and Ross [26] and Applebee's [27] operationalization of Bruner's scaffolding concept, we can observe differences in approach. Whereas in the former the focus is on the facilitator having a key role in the scaffolding process as enabling and facilitating learning and guiding the learner through the process towards ideal scenarios, Applebee's model emphasises a mix of aspects ranging from student control over the learning event, the quality of the task set, the importance of the contextual learning environment, aspects of team work and also the transfer of control to the student learner. It may be argued that the latter is more learner-centred and hence here we follow Wood, Bruner, and Ross [26], given our use of a strongly structured, facilitator-led process.

Even more specifically in this context, Puntambekar and Hübscher [19], referring to Edelson [28] and Edelson et al [29], describe how the visualization and modelling capabilities of software tools have been used to help students in scientific learning, with some of these tools embodying a variety of types of scaffolding: *supportive scaffolding*, in the form of examples and hints of what to do next, 'faded' by e.g. a 'stop reminding me' button; *passive scaffolding* activated by help buttons that provide contextualized help or examples on request; and *reflective scaffolding* that promotes reflection on the task by providing prompts in a notepad window where students can input text [19]. In section 5 we discuss these ideas in relation to GRIP and the use of software in helping to create lower GHG visions of the future with the wider public.

3. Backcasting

We explain below that GRIP is a scenario backcasting tool. As Swart et al observe [30], scenario approaches are a useful framework and methodology in sustainability science, where social, economic and (semi-)natural systems interact; where integration and long term perspectives are required, where uncertainties abound; where qualitative and quantitative forms of information both have a place; and where communication with non-experts is required. A now well-known approach in scenario studies is backcasting, which entails the definition of a desirable future and then working backwards from that future to the present in order to plan how this might be achieved (pioneered in an energy context by Lovins, [31]; adopted by e.g. [32], [33]). Since the early days of backcasting, the approach has become more popular and more widely applied over the last decade. Backcasting is explicitly normative, growing out of discontent with forecasting based on trend extrapolation, with its assumptions of on-going increase in demand and (in the early days of energy modelling) a disregard for renewable energy technologies and energy conservation [34]. This is not to say that a backcasting approach cannot include the use of predictive techniques during a process of determining options by which a desired end-point might be achieved [35]. The overall approach of backcasting, though, remains fundamentally different in its orientation from forecasting.

Related to this, backcasting is generally more amenable to social participation than is forecasting. This need not be an inherent characteristic – it is possible to backcast without social participation and it is possible to forecast with social participation. In practice, though, backcasting lends itself to the direct or indirect involvement of a range of norms because it is inherently more open to alternative pathways. Variety can in principle be a feature of forecasting via the use of alternative assumptions. Forecasting can also make use of more than one model, allowing subsequent comparison. However, the available options are constrained relative to those provided by a backcasting approach. Forecasting is largely model-led: if the model cannot accommodate a perspective or an assumption, it will by necessity be excluded from the modelling process. In contrast, backcasting challenges participants to find appropriate tools for the purpose. It need not begin with those tools as pre-defined (though it may). This is also not to ignore the potential downsides of stakeholder participation in scenario modelling: stakeholder participation may, for example, contribute to path-dependency due to the participants safeguarding vested interests [36]. Nonetheless, a backcasting scenario process offers the potential for social learning in a given context [34]. Our purpose here is to point to some of the cognitive processes and enabling techniques that may facilitate at least individual learning. Finally, in so far as GRIP has been used with participants with widely differing levels of technical energy expertise [7], the paper also connects to the call to bridge the gap between expert-led and participatory backcasting [18].

4. Objectives and methods

The empirical part of the paper comes from a suite of studies of stakeholder and public perceptions of how a UK city-region (Greater Manchester) might meet its CO_2 reduction targets. For brevity, here we use only data from the studies with the public. Greater Manchester is designated as a UK ‘Low Carbon Economic Area’, meaning that it has been identified by national government as a flagship region in terms of delivering national emissions-reduction targets. As such, the region has its own CO_2 emission targets: a 41% reduction by 2020 and a 93% reduction by 2050, relative to 2005; the 2020 target reduction relative to 1990 is 48% and indicative figures for average per capita CO_2 in 2008 (the latest available as of mid-2011) put the region at 7.1tCO_2 per capita (compared to a UK average of 8.7t) [37]. The targets are derived via sector-specific downscaling from national scenarios undertaken for the national Climate Change Committee 1st report, the latter body having a statutory remit to advise the UK government on climate change policy. The above absolute emission values are based on production-based accounting of CO_2 only; consumption-based (i.e. embodied, including imported) emissions data places the GHG footprint of Greater Manchester citizens at 15.7tCO_2e per capita, similar to the UK average [38].

Understanding and documenting both public and stakeholder opinion and experiences provides the opportunity to take these into account when designing corresponding policy. In this case, the results formed part of a parallel energy planning process by and with local agencies [39]. The stakeholder workshops had the additional objective of engaging and informing those with relevant responsibilities in areas of transport, energy and water utilities, land use planning etc, in commercial and non-commercial organizations in the region [39].

Specifically, the workshops with the public were designed so as to enable exploration of: (a) non-expert stakeholder perception of what constitutes ‘acceptable’ emissions contraction scenarios in terms of rate of emissions contraction and the energy technology mix for residential dwellings; and (b) facilitate understanding of the learning processes involved. Related work [40] informed the format of information provision and response evaluation; our approach to relating theory and empirics is retroductive in the sense of applying explanatory theory after data collection, to help explain findings [41]. A day-long (6 hour) focus group design was used to reveal the issues that arose; recruits were social class ABC1 [42], gender balanced and of mixed age, recruited by a market research company working to Market Research Society standards [43]. There were with 8-10 individuals in each group. The results of four focus groups centering on scenario generation are used below: three with homeowners and one with landlords, all from Greater Manchester. Home ownership and inclusion of landlords were intended to elicit plausible but potentially contrasting perceptions. Using the GRIP scenario tool, each workshop produced a scenario of how Manchester might meet its GHG reduction targets for domestic dwellings, with group discussion and close moderation by the facilitator (one of the authors).

In terms of the rationale for examining public perceptions and learning, the public play the roles of both citizens and consumers, installing (or not installing) technologies and providing varying degrees of support for energy transitions policies: understanding societal views, perceptions and experiences is important in seeking a public mandate for policy. Learning in its broadest sense is assumed to be a necessary (though not sufficient) condition for that support.

The public groups were given the hypothetical brief of advising regional decision-makers on the delivery of emissions reduction targets in the residential sector, drawing on their own views of the available options. The residential sector was selected principally because there is relatively little information on UK public attitudes to microgen and related energy efficiency technology, and even less in the context of public opinion of emissions contraction scenarios. Participants were encouraged to think in terms of direct energy consumption in their own homes; the energetic aspects of transport, food, clothing and other purchases were excluded from consideration for simplicity.

As stated, given the facilitator-led style of focus group, our scenario development process can be mapped to the stages set out by Wood et al [26], creating a process that guided participants through six stages of information provision and opinion elicitation. First, a short introduction to anthropogenic global warming was provided as a rationale. Second, participants were given a set of factsheets describing some key macro electricity generation technologies <annex A> and energy options for the home <annex B>. They were asked to read the factsheets and rank the options in terms of their preferred order for implementation. Third, they were asked to arrive at a group view of which electricity generation technologies they would prefer to see implemented and to also review their earlier, individual choices. The fourth and fifth stages followed a similar structure to the second and third, but with a focus on technologies for home (domestic-level) energy generation and energy efficiency. At this point respondents again completed the technology ranking exercise. Sixth, participants were taken through an energy-emissions scenario exercise for 2050 and 2020, using the GRIP scenario tool. This enabled observation of the impacts of their choices in the preceding stages. Figure 1 summarises the process, applying scaffolding concepts to the stages in the scenario generation exercise as a whole.

The discussions were recorded and transcribed and the energy technology choices and their emissions consequences recorded in GRIP as MS Excel sheets and later graphed. The technical specification of GRIP itself is described in Carney [44], with an overview also available [6]. The tool essentially consists of a particular database format populated by a location-specific GHG inventory, linked via fixed coefficients to a wide range of energy technology options, the scale of which can be readily manipulated through an interface of sliders and dials in a scenario tool[1].

5. Public and stakeholder opinion on energy options and scenarios

This section presents an overview of notable results; interpretation and discussion is in the subsequent section. Quantitative data analysis is complemented with qualitative findings as appropriate. At the domestic level, energy efficiency options were generally as the first priority, above energy generation options, a response that echoes the technical modelling of domestic emissions reduction potential [45]. The relatively high ranking of domestic solar parallels previous national and European findings ([46], [47]): above all energy options, solar tends to be perceived as a benign, clean technology. Biomass heating suffered from an association with polluting activity, though those who had practical experience of a modern biomass boiler took a more favourable view. Concern about the noise of air heat pumps was common, though few had encountered these and the influence of the information that we gave to the participants <Annex 2> was certainly significant in this regard. Micro-CHP appeared to be poorly understood despite our provision of information, while district CHP had industrial associations. Retrofitting was widely seen as more problematic and costly than new build in terms of installing microgen.

The views of the landlord group were in many respects similar to the public groups, but with some notable differences including: being strongly financially-driven; wanting shorter payback times for investments in rented properties compared to own properties; strong interest in residential energy-related investment opportunities; willingness to accept heating technologies in rental properties that they would not accept in their own homes (such as blown air heating); more sophisticated discussion of practicalities, such as sharing hot water storage between a biomass boiler and solar thermal, and the need for new hot water storage installation, given the recent legislatively-driven push for gas combination boilers in the UK; a stronger interest in micro-CHP than in the other groups; notably less concern about biomass combustion and nuclear power and a greater appreciation of the potential of hydrogen for storage/balancing and CCS. While the landlords ranked the technologies differently to the extent of statistical significance, there was no such difference in their views of what would suit their rental properties and their own homes <Annex 3>.

In general cost was perceived by landlords as an incentive for saving energy and triggering behavioural change – for example: "I suppose they get the energy bill so it's in their interests to do it" and "Energy use first because of no cost to me" (landlords speaking about tenants and prioritising energy demand reduction). A further consideration was short versus long-term investment: landlords were mostly interested in short payback periods, hence relatively easy, low cost insulation measures were favoured: "Insulation is easy, you can get grants to have it done". A clear link was made between the capital cost of technology options and pay-back time: "The expensive ones only work on a long term basis, but many of us are looking for short-term", with "disruption" also playing a role for both landlords and tenants. In general a cost-benefit dialogue permeated the discussions with landlords to a much greater extent than in the wider public groups.

Regarding the macro energy technologies, in addition to generally affirming a large expansion of wind energy infrastructure (particularly offshore), participants tended to approve of the concept of a

European grid mooted in the guidance sheets, envisioning electrical import coming from southern to northern Europe generated by extensive solar PV and concentrated solar thermal arrays. Electrical generation via biomass and waste combustion also ranked highly at the macro level, despite being placed last on the domestic technology front and despite local air pollution being a concern. Advanced nuclear-based electricity generation was the power generation technology that created the largest variation in individual preferences. Fossil CCS, fossil natural gas and coal followed at the lowest end of the technology rankings, in that order, in terms of approval.

The scenario exercise required the groups to apply their learning and consideration in the morning session to deliver emissions reduction targets for 2020 and 2050. Their ideas, developed in discussion with the facilitator, were tested through use of the scenario tool - for example, participants in one group achieved a notional CO_2 reduction of 20-25% by 2020 primarily through a reduction in heating demand that they considered would be delivered first in the new build and social housing sectors and thereafter in the wider building stock, funded through national government incentives to local councils that would be passed on to the public. Overall, participants had little trouble envisaging a city scale 41% CO_2 emissions reduction by 2020 relative to a 2005 baseline, substantially made up of reduced gas consumption, changes to the electrical grid mix and on-site (in-home) power and heat generation. In delivering major emissions reductions, electrical supply, both national and on-site, was viewed as key in the provision of all energy services.

Envisaging a 90% CO_2 emissions reduction for 2050, however, was found to be much more difficult. In the public groups, difficulty in plausibly meeting the 90% reduction (despite this excluding international-transport and embodied emissions) often led to related discussion of governance and ethics, particularly issues of whether various forms of compulsion would be justifiable or acceptable. Some disillusionment, also tinged with resigned humour was also sometimes expressed when perceiving that meeting the long term national target of minus 90% would be very difficult.

The landlords envisaged reductions in energy demand of up to 20% over the first 10 years and were divided over an increase in electrical heating. In terms of macro supply in their scenario, on- and off-shore wind accounted for 41% of electricity generation and nuclear accounted for 19% <Annex 4>. At the micro level, ground source heat pumps were viewed as preferable to air source due to the noise anticipated from the latter. Micro-CHP was viewed as having some appeal to the extent that it replaced a boiler, but it was also considered unfeasibly expensive. In general, demand reduction through insulation and approaches including behavioural change featured highly, as did CHP and domestic solar thermal.

In terms of the scenario output by the public there were strong commonalities, driven to some extent by what is technically possible in the timeframe. Figures 2-4 summarise the scenarios generated by the public: the chart at the top of each Figure shows the envisaged macro electricity generation technology mix for 2020 and 2050, the middle chart shows the envisaged energy technology mix for domestic residences and the lower chart shows envisaged residential electricity consumption by source. In all groups, the production of electricity from the National Grid became by necessity largely carbon free: where electricity was produced using fossil sources, this was usually combined with Carbon Capture and Storage (CCS) (no coal use was assumed). In two of the three scenarios, electricity consumption sourced from the National Grid reduced over time, displaced largely by a greater uptake of on-site renewable technologies and Combined Heat and Power (CHP) units. As can be seen in Figures 2-4, the emissions reductions achieved were largely similar by sector in each group, again raising the issue of apparent technological necessity or determinism: despite an apparently large range of technological options, the need for large scale emission reductions seems to force deliberative groups into a relatively limited range of choices.

<Please insert Figures 2, 3 and 4>

Our experience is that building emissions reduction scenarios with GRIP helped participants to understand the scale of change required to meet the near-term emissions reduction targets and what may be required to bring about those changes. Participants did not treat the scenarios as hypothetical contexts, but endeavoured to be realistic in their judgments. In fact, the qualitative analysis of the data supports this point insofar that the feasibility of the measures was a key issue for most participants. For example in relation to micro-CHP: “It seemed reasonably possible to get it done….” and “first is insulation, as it seems the most economical way of keeping in heat and it’s not mad expensive. One of the do-ables…” (public group). A further comment on CHP: “So if you had an industry down the road it would be suitable for that?…so it would be more suitable for new buildings then?” The latter also highlights a potential readiness, willingness for the participants to question and revise existing views and change existing perceptions about what is possible and suitable – at least where this did not conflict with some other priority or value.

6. Discussion

6.1 General observations

Learning is without doubt a complex, multifaceted phenomenon. Through the scenario generation processes we observe the potential for a variety of types and drivers of learning, including what might be termed enforced learning through legislation and regulation; learning through semi-voluntary, financial incentives; and voluntary learning through insight, through change in awareness. Regardless of whether learning is enforced, semi-voluntary or voluntary, such learning takes the participant out of his/her usual comfort zone and has the potential to trigger change in habits. Very few of the participants in the GRIP scenario processes had prior experience of energy-emissions modelling and many lacked awareness of these issues. Much as Bruner prescribed, through the day-long sessions, participants were incrementally enabled to build an understanding of some of the factors involved in achieving emissions contraction, specifically relating to energy technologies. They were also provided with the means with which to model this, including the means with which to see the results of that modelling in real time. Participants were treated much as Bruner's 'logico-scientific' thinkers [48] (though we refer to other cognitive approaches below) and used the same software as is used by agencies to compile emissions inventories in several countries [7]. Artefacts used to assist in the scaffolding consisted of 'fact sheets' and the software itself, used in the context of group discussion. In addition running through the experience as a whole was a narrative of significance and urgency, with commentary and interpretation provided throughout the day.

6.2 Barriers to learning

In addition to learning, there was also considerable persistence in attitudes and behaviour, at least in the initial phase of information provision. This included the persistence of negative attitudes, expressed in terms of risk, aesthetics and environmental impact (e.g. "dangerous", "not popular", "futuristic", "hazardous", "ugly" , "huge"), often with striking, sense-based attributes (in terms of noise, smell, vision - e.g. onshore wind turbines as "eyesores"). Generally, attitudinal persistence is understood as antithetical to both attitudinal and behavioural change; for example: "Difficult when you've got used to a certain way, to change back to how things used to be" (house owner). Some participants rationalised their unwillingness to change in generational terms: "Maybe it's too late for us but we need to educate future generations".

Figure 5 shows the ranking of individual, residential-level technologies by the public before and after considering the factsheets; the Figure also shows the technology ranking by the landlords in terms of deployment in their own home relative to their rental properties (1 is the highest or best rank, 10 the lowest or worst). While there are some before/after differences and own home/rental home differences, these are not statistically significant <Annex 5>. Rather, it is the ranking differences between technologies that are significant and what is most striking above all is the commonality of opinion between groups and over time (the latter for the public groups). In other words, provision of information and discussion of this did not shift attitudes to individual, domestic-level technologies. In contrast, obliging participants to meet stringent climate targets did lead to their use of the more controversial of the lower carbon macro technology options. We did not measure attitudes to individual technologies at the end of the scenario session and so it remains an open question as to whether or not the mean ranking of nuclear as a macro option may have shifted to the positive by the end of the exercise. It should be noted that the participants omitted completely the non-CCS fossil fuel options from the 2050 options (Figures 2-4).

<Please insert Figure 5>

The finding of attitudinal persistence through the period of scenario generation processes brings into question the capacity of such processes to generate attitude and behaviour change as an expression of new understanding or knowledge. It also raises the issue, as mentioned, of technological necessity as a potential constraint on deliberative outcomes. Participants were obliged to envisage technology mixes that they did not necessarily prefer, as they struggled to approach a 90% reduction in CO_2 emissions by 2050. This dissonance or disconnect was less evident for the interim scenario date (2020).

Moreover, as scenarios are often developed with the objective of organisational learning [16], attitudinal persistence raises the issues of what can be expected to be learned, which types of attitude can be expected to persist, which types of individual or organisational behaviour can be expected to change and how these processes can be accounted for theoretically. Further issues include how related processes might interact with attempts to provide learning-oriented scaffolding, pre-existing worldviews and the wide range of variables known to affect attitudes (often classified in terms of the characteristics of messenger, channel, message and receiver [49]. The attributes associated with these are wide ranging and the literature extensive (see e.g. [50] and in an energy context [51]).

It is unlikely that conceptual models developed to account for attitude and behaviour change in general can fully capture the change processes involved in scenario development contexts. For example, to take a model that emphasises cognition (to which scaffolding relates), the Elaboration Likelihood Model [52] postulates that enduring attitude change is more likely to follow when individuals give careful consideration to information. Yet our participants spent several hours considering options for GHG emissions reduction without much change in their initial attitudes to individual energy technologies. Below we consider just some of the many possibilities that arise in terms of further work as a result of this and other considerations.

6.3 Further work

One aspect of learning that merits further investigation is the extent to which there is a shared understanding – implicit in the ZPD and scaffolding concepts [53] – of the rationale, objectives and value of both the exercise and of emissions contraction per se. This might include assessment of perceptions of the extent of the environmental threat: perception of a high environmental threat can be positively associated with a propensity to engage in pro-environmental behaviour [54] and may feed through to perception of greater plausibility for higher emissions reductions. Relatedly, reactions to the difficulty in reaching -90% CO_2 by 2050 would be of particular interest, including whether participants felt that they stretched plausibility in these efforts, or whether they discounted the views of the two generations beyond their own. Alternative framing of the information provided to participants would also likely have some influence on threat perception: in this case we did not detail the risks associated with a business as usual global GHG emissions trajectory.

Another potential aspect of participative scenario generation processes that merits closer investigation, particularly in this case, is the extent to which, and the manner in which, any software or other technical aids function in the role of scaffolding as conceived by Bruner. In the present case, use of GRIP was centrally-led as part of a group process. The participants were free to express their views and those views were recorded and welcomed; they were also encouraged to experiment with GRIP under the facilitator's guidance. However GRIP is not designed for a complete novice to use immediately: it includes too many variables for this, many of which will be wholly unfamiliar to lay users. For this reason much of the scaffolding support has to date come from the facilitator, who maintains an engaged, interpretative commentary that guides the group. One can imagine in future, more individualised forms of supportive scaffolding in the sense referred to by Puntambekar and Hübscher [19] above, in which the software plays a more active role in guiding and informing. GRIP or equivalent calculators might also be tailored to more specific contexts or sectors.

It is also worth considering the extent to which the software meets the five criteria for effective scaffolding proposed by Appleby [27]. In terms of learner ownership of the learning event, the GRIP scenario process does allow participants to make their own contribution to the activity as it evolves, although GRIP itself can at present only incorporate numerical information. In terms of the appropriateness of the instructional task, the large majority of users appear to find the process manageable and useful in terms of learning, but occasionally lay users do perceptibly struggle and the degree and types of learning at an individual level certainly merit closer investigation. In this connection it is worth noting Dewey's emphasis on linking new learning to familiar aspects of a student's environment *55+: GRIP itself deals with abstract units that need to be explained and interpreted for some users. In general the role of the facilitator in connecting GRIP to everyday experience is critical. In terms of providing a structured learning environment, while the sessions with lay users did first provide accounts of macro and micro energy options before requiring users to apply this knowledge, the software is not explicitly instructional in design (though it has this potential). Nor does the software attempt to measure the extent or rate of learning by individuals, at least as presently designed. In terms of shared responsibility, the task of establishing plausible emissions contraction scenarios is solved jointly and collaboratively with the facilitator in an instructional role, much as Appleby [27] envisaged. Finally, transfer of control, in which learners gradually take greater responsibility for progress, is only fully achieved in single-user contexts. In group contexts, participants are initially and encouraged to experiment individually for a short period, followed by the input of group-agreed values by the facilitator.

In terms of other potential research directions from cognitive psychology, possibilities include mental maps and models [56] or gestalts [57]: concepts that offer different but related accounts of learners' connections between elements learned. To this can be added sociological concepts such as Moscovici's social representations [58], denoting shared understandings, and anchoring as a description of the way in which individuals make sense of new ideas and information in relation to their existing knowledge. Other possibilities include attention to the role of affect and the sensual side of learning and the learning and unlearning. Similarly the role of narrative in engaging interest and in communicating knowledge was recognised by Bruner in his later years [48] and has been a focus of attention in the context of computer-assisted learning [59].

6.4 Limitations

The above notwithstanding, it is also the case that while providing a high degree of structure allows participants to be closely guided, this may also have some disadvantages. For example, initial 'lay' conceptualisations of energy supply and demand may be obscured by the terminology that participants are provided with. The selective information in the fact-sheets and the abstract scientific units used in the software will inevitably condition participants' thinking and perceptions. For example, to our knowledge, no participants had direct experience of air source heat pumps and hence their perception of the noise of these was inevitably and directly influenced by the information that we provided. While we were aware of related noise reports – e.g. [60] report a range for air source heat pumps of 59-76dBa at 1m distance – few participants would otherwise be aware of this. Nonetheless, as is evident from Figure 5, some of the participants' own views did persist through the sessions and this would likely be the same in other usage cases.

Finally, it should also be recalled that while we are here concerned with learning principles, learning is only one aspect of a scenario development process. There are, of course, also substantive political issues at stake, particularly in terms of willingness to modify lifestyles in order to achieve energy demand reductions and also in relation to paying for energy-related investments, directly in the home and indirectly through utility bill increases. Moreover it should be recalled that participants were voicing opinions in a hypothetical context, though generally their level of engagement in the scenario generation process was high and overall we have found these processes illuminating and suggestive of much further work.

7. Conclusions

Approximately 40 members of the public in four separate groups, each convened for one day over May-September 2010, gave their views of macro and micro generation technologies in the context of long term government targets for emissions reduction. All public participants were home owners from Manchester, with one group being landlords. Each of these groups followed the same research design, being provided with initial information on macro and micro lower carbon energy technology options; a pre- and post-group questionnaire designed to identify technology ranking and any opinion change; and group discussion of how to reach a 42% CO_2 reduction target by 2020 and a 90% reduction target by 2050, using the technologies, in ways that the group considered feasible, assisted by a domestic household version of GRIP emission scenario software that shows the emissions consequences of different energy technology choices with respect to a recent baseline for (in this case) Manchester. The stakeholder groups followed the same design but omitted the initial information provision.

The combination of a ranking exercise informed by information sheets, plus use of a domestically-focussed version of GRIP, have proved useful in both helping the public understand the emissions implications of micro-generation technologies and energy efficiency and in generating qualitative and quantitative information on perceptions and learning. Our experience in introducing non-specialists to energy and emissions modelling has led us to look at learning theory that can assist in designing scenario development processes. At a superficial level, it is clear that the use of simple dials, sliders, immediate feedback and an interpretative commentary help to explain a high level of participant engagement and understanding. As with any emissions calculator, GRIP abstracts and simplifies from an array of socio-political and economic complexities that surround energy system transformation. In this respect the process follows learning principles that Bruner began to develop over 50 years ago. Central to these principles, still strongly influential today, is the concept of scaffolding developed by the Soviet psychologist Lev Vygotsky some 80 years ago [61].

There are many possibilities in terms of directions for future research that build upon the above, not least because there are many alternative approaches to theorising learning and there is limited literature on learning in the context of scenario building. In future we propose to explore some of the themes that have arisen in the present study, as we seek to add to the surprisingly scant literature on energy and other scenario-based learning.

Note

1. The interface can be experimented with via the 'sample tool' link on the project website: http://www.getagriponemissions.com/index-cycle.html

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Figure captions

Figure 1 Applying the scaffolding steps of Wood, Bruner and Ross (1976) to the scenario process

Figure 2 Scenario output from public focus group 1: national electrical grid mix, domestic energy technology mix and electricity source

(note: pellets/liquid/solid are alternative forms of biomass fuels for heating)

Figure 3 Scenario output from public focus group 2: national electrical grid mix, domestic energy technology mix and electricity source

(note: pellets/liquid/solid are alternative forms of biomass fuels for heating)

Figure 4 Scenario output from public focus group 3: national electrical grid mix, domestic energy technology mix and electricity source

(note: pellets/liquid/solid are alternative forms of biomass fuels for heating)

Figure 5 Ranking of domestic energy technologies by participants (10= worst, 1=best)