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The reflexive scientist: an approach to transforming public engagement

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Abstract Calls for greater public engagement with science (PES) are widespread, but there appears to be little agreement on the meaning and purpose of engagement across the various actors calling for it. This reflects a persistent gulf between PES scholars and scientists communicating with the public. We argue that direct engagement between PES scholars and scientist-communicators could, by facilitating greater reflexivity, lead to a step-change in the calibre and clarity of activities that are designed to support enhanced public engagement with science and technology. In this paper, we, as authors beginning from different perspectives, explore the potential of, and barriers to, a conversation between critical social scientists and members of the science community about public engagement. We demonstrate how and why the PES literature does not "speak for itself" to scientists but provides a starting point for conversation rather than a substitute for it. We then explore what reflexivity might mean for PES and argue for three important foci: political-economic context or politics of the field; institutional context; and personal assumptions. We then discuss barriers to, as well as strategies for, fostering such reflexivity, concluding that new models of authorship and publication are needed if this promise is to be fulfilled.

Keywords Science communication · Public engagement with science · Science outreach · Reflexivity · Reflexive scientist

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Introduction

Calls for greater public engagement with science (PES) are widespread. There appears to be little agreement, however, on the meaning and purpose of engagement across the various actors calling for it. Within the social-science literature, a key recurring theme has been the need for a shift away from the "deficit model" of communication, in which it is assumed that public *support* for science (especially controversial science) will be achieved through better public *understanding of* science, and that this in turn can be achieved by addressing an apparent knowledge deficit with an injection of scientific information and explanations. In place of this model, many social scientists advocate more dialogic forms of public engagement with science (and scientists' engagement with the public). Such forms of engagement would, among other things, provide opportunities for public participants to identify non-technical factors relevant to evaluating a scientific project and/or to contribute otherwise neglected but valuable local and practitioner knowledge. These processes, sometimes characterised as the co-production of knowledge,[1] are argued to be particularly critical for addressing problems of environmental sustainability (Pohl et al. 2010; Bäckstrand 2003).

[1] The concept of co-production has at least two different meanings. What Jasanoff has termed 'the idiom of co-production' refers to the ways in which natural and social orders are 'produced together': '[w]hat we know about the world is intimately linked to our sense of what we can do about it, as well as to the felt legitimacy of specific actors, instruments and courses of action' (2004: p. 14). Research utilising this meaning of co-production looks to make explicit the generally obscured relationship between what we take to be the (given) natural world, on the one hand, and the social world of humanly created institutions and power relations, on the other. In transdisciplinary research, co-production refers to a deliberately interactive and collaborative process involving both academic (certified "expert") and non-academic actors, with their different types of knowledge (Gibbons et al. 1994; Mobjörk 2010; Pohl et al. 2010). We are using co-production in this latter sense.

There is little evidence, however, to suggest that this reconceptualisation of the "problem" of "deficit in understanding" as the need for "dialogue and engagement" has taken hold beyond the PES literature (Davies 2013).[2] For example, there is a stark difference between the assumption by many scientists that the goal of communication is to raise awareness, transmit the importance of science or correct misconceptions and the assumption in much of the PES literature that the goal of engagement should be to enable democratic publics to influence decisions about the development and use of science and technology (Besley and Nisbet 2013; Kreimer et al. 2011; Davies 2013; Stilgoe et al. 2014). While social scientists in this field have sometimes attempted to engage directly with scientists and government agencies, and while collaborations between scientists and social scientists are on the increase (if still relatively rare), the literature in this field (or concepts therein) remains largely unknown to the scientists who are involved in communicating their science to the public (Davies 2008).

We suggest that one step toward transforming public engagement for environmental sustainability would be to address the underlying assumptions of those involved in developing both theory and practice related to public engagement. To do, this, we need a genuine dialogue between social scientists, scientists, and other science communicators on this topic. Such a dialogue must involve more than social scientists simply "correcting" scientists' communication efforts—i.e. enacting their own deficit model (Irwin 2014).

Several studies suggest that scientists do not see communication as a core part of their jobs (e.g. The Royal Society 2006). We do not address that in this paper; rather, we restrict our discussion to the communication practices and underlying assumptions of those scientists who choose to communicate science, and of professional science communicators who are trained in science. In order to differentiate these activities from those carried out by people trained in PES, by institutional public-relations offices, or by the growing pool of professional engagement consultants, we refer to communication activities by scientists and science-trained communicators as "science outreach", and to the people who initiate or carry out these activities as "scientist-communicators". Over the last decade, the term "science outreach" has become more common across the science community (e.g. Leshner 2007; Varner 2014) and is often used to define, encompass, or acknowledge the wide variety of communication activities in which scientists engage.[3] The wide acceptance of this ill-defined term is demonstrated by the existence of committees with a mandate to focus on "outreach" along with either one or both of "education" and "communication" (e.g. Salmon et al. 2011). In this context, outreach should be seen to encompass both one-way "communication" and two-way dialogue, or "engagement" activities, between scientists and different publics. Adoption of the term "engagement" would assume that the activities include dialogical interaction where this may not be the case. From hereon, we refer to communication activities by scientists as "outreach" in order to remain true to their original (ill-defined) form.

Inviting scientists into a conversation about themes in PES scholarship is a critical first step towards catalysing transformative change in our approaches towards both science outreach and public engagement. There are several reasons for this, perhaps the most obvious being that it is generally scientists (and not PES scholars) who are actually involved in outreach activities. Moreover, these activities are surprisingly under-studied. Literature in science communication (e.g. Weigold 2001; Falchetti et al. 2007; Jensen and Buckley 2012; Mayhew and Hall 2012; Lin 2013) and informal learning (e.g. Bauer et al. 2007; Lehr et al. 2007; Osborne and Dillon 2007) tends to focus on the target publics and methods rather than the communicators. The PES literature from within science and technology studies (STS) also tends to focus on publics, although from a more critical and constructivist perspective, as well as on mechanisms of public engagement and their impacts, rather than on scientists representing science to the public (e.g. Irwin 2001; Einsiedel et al. 2001; Goven 2003; Lezaun and Soneryd 2007; Michael 2009; Thorpe and Gregory 2010; Felt and Fochler 2010; Powell et al. 2011).[4] There is also an emerging literature that explores scientists and public engagement, through examination of a range of factors such as demographics, seniority, academic achievement, discipline, and personal motivations and attitudes[5] (e.g. Poliakoff and Webb 2007; Jensen et al. 2008; Dunwoody et al. 2009; Besley and Nisbet 2013; Besley et al. 2012; Jensen 2011; Kreimer et al. 2011; Wilkinson et al. 2011; Torres-Albero et al. 2011; Crettaz von Roten 2011). Across all these fields, however, there is a tendency to treat "science" in an undifferentiated way, for example, not distinguishing among the different institutional and political contexts in which scientists work and communicate with the public. This can lead to alienation of individual scientists attempting to engage with this literature, as discussed in more detail below.

A further reason for making greater efforts to include scientists in the conversation about PES is to clarify and define explicit and implicit assumptions by scholars in different

[2] The extent to which the terminology of "dialogue" and "engagement" has been embraced while various "deficit" explanations for public opposition to particular techno-scientific projects are reformulated in slightly different guise is a relevant but separate issue, which we do not explore here. See, for example, Wynne (2006).

[3] These activities are a sub-set of the full spectrum of professional and voluntary "science communication" activities that are carried out not only by scientists but also professional science media and educators.

[4] See Wynne (2014) on the lack of attention to "science" within the literature on "public understanding of science".

[5] Related papers can be found in the Special Issue of *Public Understanding of Science* on "Mobilization of scientists for public engagement activities" introduced by Bauer and Jensen (2011)

disciplines about the purpose and goals of outreach and public engagement with science. This is not to say that if only scientists were familiar with the PES literature, they would change their goals and assumptions to match those of the PES scholars (which are, in any case, not uniform). Indeed, some may respond by denouncing that literature (e.g. Kuntz 2012). Others may be too wedded to the notion of science as by definition apolitical to consider any alternative view. Still others may draw on their own experiences to contest the assumptions and assertions contained in the PES literature. Thus, we suggest the PES literature itself would also benefit from more direct and extensive engagement with scientists on the subject of public engagement. We hold, however, that if a conversation is to happen at all between these parties, it must start with mutual acknowledgement and understanding of how the role of these activities is differently understood.

Bauer and Jensen (2011) have argued that it is "important to foster a reflexive attitude" towards public engagement, and that research into public understanding of science "has its role to play in this, pushing scientists to think about their activities, their implicit vision of the public and the interactions between science and society." In this paper, we explore a pathway to this reflexive attitude through an examination of our own efforts (which are ongoing) to foster reflexivity. We sought not only to "push" the scientists, but also to improve the social scientist's understanding of the experience of being "pushed" in this way. We did this both to identify our own assumptions and limitations related to interdisciplinary collaboration, and also to identify insights and processes that might be applied more widely.

Irwin (2014) calls on the PES field "not [to] consider practice and critical reflection as separate activities but take 'reflective practice' and 'practical reflection' equally seriously". We argue that "reflective practice" and "practical reflection" require direct engagement between the social scientists who focus on reflection and the scientist-communicators who focus on practice. This collaboration would lead to theory that is informed by the challenges of real world activities, and practice that is informed by critical reflection. We believe that this could lead to a step-change in the calibre and clarity of activities that are designed to support enhanced public engagement with science and technology.

A journey towards reflexivity

The three authors of this paper are, respectively, a scientist, a science writer, and a social scientist. The first author of this paper (whom we describe herein as the "scientist") is an atmospheric chemist and science outreach facilitator, with a positive attitude to outreach, who works in the field of climate change and has coordinated international, national, and regional public outreach efforts (Salmon et al. 2011; Salmon 2013a, b). Eighteen months prior to first submission of this paper, she received an internal grant, from the Faculty of Science at which she is employed, to "identify and adapt a methodology by which formal and informal science-centred outreach and education initiatives can be evaluated with respect to the expectations and learning goals of the expert individuals, organisations/funding bodies, and audience/learners." The desired outcome was "the establishment of a robust research method, and a recommendation for standardised success markers, by which science-centred education and outreach initiatives can be evaluated" including establishment of "a method for objective evaluation of science-led outreach and education initiatives". [6] In her community of polar and climate science, public outreach was common, celebrated, and always understood to be a "good thing", albeit often professionally unrewarded.

In the development of this project, she established collaborations, separately, with the two other authors of this paper. Seeking advice on methodology for this research, she first approached a political theorist and social scientist (the "social scientist") who has expertise in public dialogue around biotechnology and who has been critical of motivations for engaging the public with science (Goven 2003; Goven 2006a, b; Goven 2008). The social scientist had a significantly different perspective on science and the science system, having devoted considerable effort to analysing, and criticising, communication (and other) practices in the biotechnology sector. For both researchers, this was the start of a journey that explored contrasting and sometimes conflicting assumptions about the purpose of public engagement, in the process highlighting the different political (and political-economic) dimensions of different fields of science. This conversation was then joined by the third author, a science writer and historian (the "science writer") who trained in geology and the history of science and who has uncovered surprising and significant changes in public attitudes towards nuclear science and technology in New Zealand through the second half of the twentieth century (Priestley 2006, 2010, 2012) .

Using our different disciplinary training, and expertise in three fields of science that have been controversial for very different reasons, we began to explore the potential for, and barriers to, a conversation between critical social scientists and members of the science community (including both practising scientists and science communicators, many of whom are trained in science) about public engagement. Recognising that the mutual misunderstandings we experienced were likely to have broader relevance to the cause of transforming (or even evaluating) science outreach, and particular relevance to the question of whether outreach practitioners should be expected

[6] While these ambitious and potentially naïve goals were not realised, this project did lead—somewhat unexpectedly—to an ongoing research collaboration and the exploration of reflexivity documented in this paper.

to familiarise themselves with social-scientific scholarship in PES, we decided to embark on an auto-ethnography of the experience of reading literature in PES.

Reading the literature

The training of many scientists—and science communicators—has resulted in their understanding "science" in a particular way: science as a systematic process of observation and experiment that leads to deeper understanding about the structure and nature of the physical and natural world; and the scientific method as being based on developing and testing hypotheses and on principles such as falsifiability. This contrasts significantly with conceptualisations by many social scientists, who are more likely to understand science as a social activity, not exempt from the kinds of social influences, processes, and tendencies found in other spheres of activity; and/or to see "science" as a discursive resource used to legitimate the agendas of those with particular political or economic interests; and/or to challenge the distinctiveness of science by pointing to differences between common representations of science and science-in-practice.

These differences, which may relate not only to scholarly disciplines but to aspects of personal identity, can greatly complicate engagement between scientists and social scientists. Thus our "reading the literature" experiment was underpinned by a period of building trust by finding areas of mutual agreement and by gentle interrogation of topics on which we disagreed. On several occasions we had to clarify when our responses felt emotional or criticisms personal. This process took time, and required good humour, shared meals, and patience.

As the formal part of our experiment, we read six articles (Irwin 2014; Jasanoff 2014; Nowotny 2014; Stilgoe et al. 2014; Sturgis 2014; Wynne 2014) from a recent special issue of *Public Understanding of Science* that reflected on the past 20 years of research in the field, recorded our responses, and then compared them. As might be expected, the social scientist familiar with this field found very little with which to disagree in the articles, and nothing at all startling, unless it was the degree to which some of them seemed to be stating the obvious. This experience differed radically from those of the scientist/outreach coordinator and science writer/historian. While the responses of the two authors with training in science were far from identical, they did have some important elements in common. The first of these was frustration.

One source of frustration was the language of the articles, which was experienced as dense and obfuscating. "I find it astounding that these are some of the people who criticise scientists for using jargon," said the science writer. Words or phrases experienced as obfuscating included: scientism and scientistic, governance (as in governance of science), political imaginaries, deliberative democracy, and normative. Lack of familiarity with these terms also sometimes led to misinterpretation, which in turn resulted in serious misunderstandings, as discussed below. While the social scientist has herself been exasperated by the proliferation of jargon in social-science studies of science, these terms would not have been classified as such by her and thus may well not have been avoided by her in efforts to communicate with scientists. As some of these terms represent key ideas with which social scientists think scientists must become familiar if they are to be "dialogue-capable",[7] our experiment suggests that efforts to achieve greater clarity are imperative if a shift to engagement is to occur.

A second source of frustration was that what they saw as criticism of science communication practitioners was not accompanied by helpful advice about how they might do things differently and therefore avoid the pitfalls that are the focus of much of the critical PES literature. Wynne's temptation to define the 20 years of PES as a process of "'public disorientation by', not 'public understanding of', science" (Wynne 2014) was seen as problematic as it was not accompanied by any practical advice on how to do things better. When Irwin expressed frustration at the lack of progress in two decades of PES, and suggested he convert his "blurred old overhead transparencies to PowerPoint and give the same presentation" on the theme "from deficit to democracy?" (Irwin 2014), the science writer requested that he do exactly this, "but this time reframe it and present it to us scientists and sci-commers". While sympathetic to calls for better-informed science communication and outreach practice, they sought advice on *how* they might accomplish this in their own activities.

In addition to frustration, the scientist and science writer felt attacked by some of the literature and experienced anger and resentment in response, illustrated by sentiments such as: "I was left feeling like there was still an us and them thing going on, and as far as he was concerned I was one of the 'thems'". In some cases, this was a result of misunderstanding produced by lack of familiarity with concepts and terms. For example, "scientistic" was interpreted by the scientist and science writer as "doing things like a scientist, or in a scientific way". Thus, a phrase like "the political problem of scientism" (Wynne 2014) was experienced as a problem with scientists and the way they did science. On the other hand, the social scientist did not read these criticisms as attacks on scientists in general, but rather as criticisms of public actors (politicians, regulatory bodies, or "public" scientists such as a government's chief science advisor) who inappropriately extend the jurisdiction or authority of "science".

Our experiment surfaced these misunderstandings and led to long—and ongoing!—exchanges about the meanings of these terms and the history and targets of critical PES literature. As the scientist remarked: "that's why 'we' scientists get so

[7] We thank an anonymous reviewer for this term

confused when 'science' is attacked … because in fact it's the governance and politics and economy of science that's being attacked, and possibly the creation and funding of our positions, but not our individual practices (usually). It would be really helpful if that was clarified."

Clarification of terms is intertwined with clarification of goals. As an example, in response to Stilgoe et al's (2014) statement that "support for public engagement is part of a broader commitment to the idea of publicly engaged science", the scientist commented, "that might be the goal for social scientists but I suspect not for most scientists—even those enlightened ones of us! What does 'publicly engaged science' mean?—not just a public who understand our science, but a science that is informed by the public. That's pretty extreme (from my background)! And possibly something at the heart of our disciplinary misunderstandings—we actually want/support public engagement for very different goals." Yet the scientist was—or became—comfortable with the approach of "reflexive engineers" (discussed below) that included "seeing publics as a resource and partners in decision-making processes [and] viewing education as a two-way process between engineers and communities" (Robbins 2007 p.100).

Exploring this issue further, we found that both science-trained authors initially had difficulties with, and objections to, the notion of a science informed by the public. They interpreted it to represent another route through which the politically and economically powerful could influence science and to entail a complete disregarding of the value of scientists' training and scientific process and data. The scientist reflected:

> As I become more familiar with this literature, I'm still extremely aware of how alienating terms like "deficit theory" and "co-production of knowledge" are to my own community of people trained in science. Even when these are the appropriate terms and concepts for a given conversation, I'm also aware of the likelihood that they mean different things to different people, depending on their disciplinary background, community of peers, and familiarity with PES. Even the term "deficit theory", which is now relatively mainstream, seems to carry very different meanings: from one-way "I know stuff that you don't" communication of any science, to a specific term that is relevant only to controversial issues. To someone who is new to the field, and genuinely trying to learn from it, this is not only confusing for its own sake, but also because in science we are used to words having very specific meanings, ones that we can look up if we don't understand them. In science, there is a right meaning and a wrong meaning. It's hard work not having those boundaries to work within.

The science writer commented with regard to "co-production of knowledge": "It's scary, because WE DON'T KNOW WHAT IT MEANS! It is so open to interpretation."

This is a further example of science-trained authors reading meanings into phrases and terms used in the PES literature that the social scientist did not expect. It highlighted that much of the language of PES could be described as "under-specified". But more than that, it highlighted a difference in orientation toward that under-specification. Among PES scholars there is often an (explicit or implicit) advocacy of experimentation and open-ended change in the science-society relationship. Concepts like the co-production of knowledge or a publicly engaged science may be deliberately under-specified as a result of a conviction that much needs to be worked out in practice. While to the PES scholar this may seem logically consistent with, and indeed required by, a goal of greater social responsiveness or democratisation, to the scientist this is understandably much more threatening. Where are the boundaries of this process? What remains of a commitment to and respect for scientific evidence and method? When specific examples of what the social scientist considered co-production were described to the scientist, they were not perceived as threatening. This suggests that PES scholars, if they want to be more persuasive to scientists, need to take greater account of how scientists will fill in the blank spaces left in these as-yet-to-be-worked-out concepts.

Our experiment also highlighted that the different personal experiences of doing and communicating science resulted in a different reaction to several aspects of the critical PES literature. The scientist, for example, carried out her post-doctoral research in Antarctica. She observed, "early on in the whole Antarctic science thing I realised that scientists were not much more than a pawn in a political game … that was made very obvious to us in several ways, so I've been comfortable with that notion ever since I became a practising scientist, I guess. In fact, I'd have been far less comfortable justifying my trip to Antarctica based on purely brilliant science—I was much happier seeing myself as a glorified park warden (if the scientists are there it keeps the military out, more or less, and we get to do some important science at the same time)". In contrast, the science writer was initially more resistant to some of the criticisms of science in the literature. Following 20 years as one of the few professional science writers in New Zealand, she felt part of the science community and had developed strong, positive, relationships with scientists in fields such as conservation biology, ecology, geology, and climate science. She shared a strong environmental ethos with many of those scientists, who often found their work at odds with profit-driven political and commercial agendas. Her response to the PES literature may have been different had she spent much of her career interviewing scientists involved in activities that were at odds with her own personal and political values.

Conflicts and misunderstandings between natural scientists and social scientists have long been recognised as a key challenge to interdisciplinary and transdisciplinary research (Evans and Marvin 2006; Bracken and Oughton 2006; Petts et al. 2008; Sievanen et al. 2012; Lowe et al. 2013). Problems of communication (such as ours) have been found to result from specialised jargon as well as from different uses of ordinary language (Bruce et al. 2004; Bracken and Oughton 2006; Dixon and Sharp 2007). We suggest that differences in interpretation of PES research, such as those illustrated above, are a fundamental barrier to PES literature directly informing the communication practices of scientists. Instead, we argue, there needs to be active collaboration and dialogue between scientists engaged in outreach and social scientists engaged in PES research.

Understanding reflexivity

The process of exploring our differing understandings and assumptions of science, and the literature surrounding public engagement with science, highlighted common terms in social science literature that were initially either misunderstood or entirely nonsensical to the scientist and science writer. Half-jokingly, one of them asked, with specific reference to the terms "reflexivity" and "praxis", "can you just stick an x in the middle to make it sound clever and social-sciencey?" It is with some irony, therefore, that we now find ourselves collectively writing a paper that explores reflexivity.

"Reflexivity" is a term used in many disciplines and contexts and does not have a consistent definition across them. In the sociology of scientific knowledge (SSK), for example, reflexivity has been used to refer to the application of the same approaches used to analyse the process of scientific knowledge production to SSK itself (Wynne 1993). In social research, it can refer to the researcher's awareness of his or her own positioning in relation to the subject of research and how this affects both what is being researched and the researcher's observations (which always entail interpretation, as nothing speaks for itself) (Anderson 2008). Generally speaking, reflexivity requires self-questioning, in particular a willingness and ability to question one's own assumptions, how they relate to societal power structures, and how they shape one's actions. More specifically, here, we use reflexivity to mean a theoretically informed capacity to critically analyse one's underlying assumptions, expectations, and positioning in relation to one's involvement in outreach. It is not simply an internal thought process, but rather a type of thinking tied to action. Reflexive thinking makes possible ways of acting that would not otherwise be possible.

More than 20 years ago, Wynne (1993) called for greater scientific-institutional reflexivity in interactions between science and the public. Wynne argues that while part of the taken-for-granted identity of science is as a paradigmatically sceptical practice, constantly questioning its own foundations, it in fact "exhibits much less reflexive capacity to problematize its own founding commitments than is supposed" (Wynne 1993, p. 334). More specifically, he says, science lacks reflexive openness about its own institutional dimensions—issues of accountability, power, patronage, ownership and control—as well as about "purposes and criteria of knowledge" and "the proper limits of instrumental control" (pp. 333-334). This, he argues, encourages public scepticism, alienation, and mistrust (p. 329).

While this call for reflexivity in science was a useful foundation to our exploration of this topic (especially to the science-trained authors, who had not come across the term "reflexive" prior to this work), we were less interested in exploring scientific-institutional reflexivity, and more interested in what reflexivity by individual scientists might look like, specifically in relation to their outreach efforts (which is not to say that the two levels—individual and institutional—are not interrelated). We found useful literature within the field of engineering, in which there is now a sub-culture of self-defined "reflexive engineers".[8] Significantly, this was also the literature about reflexivity that the science-trained authors found most accessible. Robbins (2007) describes core components of reflexive engineering as "having a holistic and flexible understanding of socio-technical dynamics; seeing publics as a resource and partners in decision-making processes; viewing education as a two-way process between engineers and communities; striving for a multifaceted understanding of social, economic, and environmental barriers to uptake of new technologies; and having an integrated approach to technological problems and solutions. Thus, reflexive engineers approach development problems with a fluid understanding of the ways in which technologies fit and co-evolve within social systems." In order to clarify how this differs from traditional engineers, he explains that "whereas traditional engineers view knowledge and society in terms of expert-led systems, reflexive engineers' views are rooted in response to public demand."

Reflexivity for PES

Building on Wynne's critique and the reflexive engineers' approach, we began to explore what reflexivity might mean for scientist-communicators. Others have explored the meaning of, and need for, reflexivity with regard to other aspects of scientists' work. For example, Fisher et al. (2006, p.485) advocate "more reflexive participation by scientists and engineers in the internal governance of technology development" as a pathway to more socially responsive and relevant technological trajectories. This requires them to become "attentive to the nested processes,

[8] N. Jeremijenko 2014, personal communication

structures, interactions, and interdependencies, both immediate and more removed" that already influence, or "modulate", the research and development process in order to be able to recognise opportunities for that process to be shaped in a more conscious (and socially responsive and responsible) way (p. 492). Reflexivity among participant researchers has also long been seen as key to the success of transdisciplinary research efforts.[9]

Here, our focus is on the role of reflexivity in scientists' interaction with the public in their outreach activities. We identified three foci of reflection necessary for scientists communicating about science in public: political-economic context; institutional context; and personal assumptions.

Political-economic context: the politics of scientific fields

Despite the fact that many scientists see their work as apolitical, science in practice is not free of power relations: scientific agendas are often shaped by economic interests and government priorities (Atkinson-Grosjean 2002; Pestre 2003; Kleinman 2003; Blumenthal 2003; Mirowski 2011). Societal challenges to dominant techno-scientific agendas are themselves often regarded as significant political and policy challenges. Moreover, science and technology have wide-ranging effects on society, raising the question of who, in a democracy, *should* have decision-making power over this domain (Jasanoff 2003; Hagendijk 2004; Brown 2009; Winner 2010; Kitcher 2011). All of these political-economic dimensions can be expected to influence whether, why, and how scientists engage in outreach. Thus a reflexive scientist-communicator would question how his or her interactions with the public are conditioned by this context.

In addition, the publics being interacted with may harbour concerns related to this context: why are resources devoted to this area of research in preference to that one? Whose priorities are shaping this? What is being foregone? Who will benefit? Who will bear the costs? What social/political choices does this trajectory embody? Some of these questions are not easily answered, but reflexive scientist-communicators would make an effort to understand this context; it is legitimate for the public to be as interested in these questions as in the technical or 'wow!' dimensions of the science that are often the focus of communication.

Here, we do not equate "scientific field" with academic discipline. Different political contexts may influence the outreach activities of scientists in the same academic discipline. To explore this, we interviewed three, mid-to-late career, male, New Zealand geologists working in scientific fields that have very different political contexts: a university professor who was lead author of a chapter of the fifth Intergovernmental Panel for Climate Change (IPCC) report, a Crown Research Institute (CRI) geologist who works on a range of commercial and government funded projects and has a part time secondment to a museum, and a freelance geologist (who also recently began part time work for a different museum).[10]

The university professor communicates to a range of audiences and through a range of media, primarily on the topic of palaeoclimate and the behaviour of Antarctic ice sheets under past climates. When asked why he engages in outreach, he stated three reasons, in order of priority. The first was a sense of responsibility: "we have an obligation as scientists to communicate what we are discovering and understanding, particularly if it has societal relevance". The second was related to the ongoing support and funding of his research institution: "showing the taxpayer and those who fund us that what we're doing is worthwhile and matters". The third, he said, was related to "an advocacy, personal side of things" to raise awareness to help to avoid the possible catastrophic climate change that could happen if we continue a business-as-usual attitude to CO_2 emissions: "I have a role as an IPCC lead author to be an ambassador for that report and to help communicate it." In that role, however, he is aware that—like many climate scientists—he sometimes finds himself communicating "in areas that I'm not necessarily a direct expert in".

The CRI geologist, whose expertise is primarily in palaeontology but who is an outspoken and regular communicator about a range of geological issues, says he shares the outreach goals of his institution to "help get our science across to the public" and "to try and raise awareness of the relevance of earth science to our society and to our economy". While he regularly speaks to a range of media and public audiences, and admits he gets "a kick out of it," he is nonetheless aware that he is responsible to and influenced by the political and commercial imperatives of his research institute. In addition to a part-time secondment to a museum, he also works on contracts for the government, and on commercial contracts that are subject to confidentiality clauses. For example, when he worked on and managed contracts between his institution and hydrocarbon exploration companies, he was not able to discuss research results with the public. These many roles, and relationships with different publics, has sometimes led to a conflict between his own beliefs and the political and commercial restrictions placed on him as a CRI scientist: "I find myself reminding [managers within the CRI] that, you know, we are a science provider and if the—if what we have to say is unpleasant then that's bad luck. If it's evidence-based we must inform." This conflict sometimes leads to "some unpleasantness behind the scenes … all organisations do get pushed around by political and commercial reality and you end up on a knife edge at times." A recent (quotable) example was

[9] For a detailed discussion of the role of reflexivity in transdisciplinary research, see Popa et al. (2015)

[10] We interviewed these geologists as part of a project titled "Science communication and public engagement: what are we trying to achieve?"

that the organisation was "instructed about what can and cannot be said in public about the [Christchurch] earthquakes". His personal opinion was that "it behoves us as a scientific institution to provide evidence-based science. End of story…..you don't withhold information just because it's unpalatable". The directive from the Prime Minister's department, however, prevented him from speaking to the media or public on this topic: "we are absolutely subject to political and commercial reality and political and commercial interference… we have to respond to how our masters would have us behave, otherwise we're in trouble … I feel really very strongly about these things, but, you know, I'm not allowed—best just to shut up."

The freelance geologist was the least affected by the politics of the field.[11] He does a lot of outreach, primarily public field trips and invited lectures to community groups, all in his own time and without payment. He enjoys doing it, saying "it's nice to be able to share information about the natural world" and hopes his work will encourage people to look "at the landscape in a different way". He's aware that his work can foster appreciation for the landscape and encourage people to better protect their local geological heritage. Being independent, there are no political or commercial leaders he needs to answer to and, at age 58, is not concerned about how speaking out might affect future job prospects. He sees it as a bit of luxury that when he's doing public engagement "I don't really hold back necessarily because I might be worried about how it will reflect on my institution or the university or whatever". His motivation to carry out outreach is "partly to do with environmental issues I guess. It's hard to say. It's kind of like information is power in a way, but if you give people more information about what their environment is and how it works and so on, they can look at the world in a different way and perhaps, yeah, they can use it in a political way perhaps, or they can advocate for their own area in a different way. Yeah, I don't really know what the flow-on affect will be, but I think education and knowledge is important."

All these geologists communicate widely about their work, but their personal and institutional motivations, and any barriers to communication, differ widely. These are just three examples used to indicate a variety of politics of field within a given discipline. This could easily become the focus of a much larger study disaggregating the politics within a given discipline. Within geology, for example, such a study might also include interviews with scientists involved in commercial petroleum extraction or the study of dinosaur fossils, to give two relevant examples.

Much of the existing literature about communication activities by scientists compares the engagement activities of scientists from different disciplines or sub-disciplines (eg, Jensen et al. 2008; Kreimer et al. 2011; Besley et al. 2012). Under such categorisation, the three scientists we interviewed would all be identified as "geologists who do outreach [of different types]". This simple categorisation, however, ignores the nuances of the specific fields within which geologists work. For a palaeoclimate geologist from New Zealand, for example, the politics around this field of research appear to include powerful economic actors obfuscating climate-change science and attacking the IPCC and individual climate scientists (Oreskes and Conway 2010); a government resistant to taking action to mitigate climate change; and the need for public support to drive action against climate change. While the first factor might discourage raising one's head above the parapet, it, along with the latter two, might also help to form a personal commitment to communicating directly with the public about climate-change research, with the aims of defending climate science from its detractors and/or galvanising public support as a counterweight to powerful economic interests blocking action on climate change. These factors might also produce real or imagined pressure from the public for the scientist to "transgress" beyond his or her particular expertise to talk more generally about the science of climate change (Nowotny 2000; Salmon 2013a). The decision to engage in outreach in these circumstances may or may not be guided by classic deficit-model assumptions. A concern for public understanding would be mixed with awareness of the influence of powerful economic interests on the representation of the science, directly and through their influence on governments, as well as the political calculations climate scientists themselves make as a result. Thus it may or may not be "the public" (or its ignorance) that is primarily problematised.

For a CRI geologist, particularly one who works on contracts related to hydrocarbon exploration, the political settings are very different. That role is likely to have a close relationship with certain powerful economic interests, enjoy support for the overall "mission" from government and face opposition to it from some political actors and a significant portion of the public. This opposition, often strongly felt and expressed, as well as the demands of commercial confidentiality, may well discourage or explicitly forbid outreach, or limit its content substantially. If outreach does occur, classic deficit-model assumptions may well come into play: that public opposition to oil drilling is the problem to be overcome, that it is based on ignorance or misunderstanding of the science involved, and a better understanding of the science and of risk management will calm fears and thus reduce opposition. Even without such assumptions, a geologist in a situation of controversy and under tight restrictions on what can be said may well default to one-way scripted communication of "information", feeling that a dialogue worthy of the name may be impossible and certainly fraught.

The freelance geologist we interviewed appeared to be the least influenced or restricted by the politics of his field. This

[11] While he works part-time for a museum, looking after their collections, he does not do public engagement on behalf of the museum although he might respond to occasional geology-related enquiries from the public.

could be partially due to not being employed by an institution, and also because his field of expertise was not controversial. However, it cannot be assumed that the politics of scientific fields are universal. Both the CRI geologist and the freelance geologist were trained as palaeontologists. In parts of the United States, evolution is contested by powerful political forces. A palaeontologist working in the US might reasonably be called upon to comment on evolution. Outreach could therefore be riskier for an American than a New Zealand palaeontologist, but at the same time might be felt as more necessary to correct misinformation disseminated by anti-evolution groups. Similarly, for a geologist working in the area of climate change, the politics of the field will shift depending on, among other things, the relevant government's orientation toward climate-change mitigation and adaptation. Thus, politics of scientific fields may well vary across nations (as well as other types of communities).

We propose that a first approach to facilitating reflexivity among scientist-communicators would be to stimulate questioning about the scientific field in which she or he operates: what are its political-economic influences and constraints, and how might this be shaping the outreach that is designed and delivered? Is he or she willing, or able, to be open with the public about these influences and constraints? If not, what are the implications of this?

Institutional context

In the 21st Century, there are few, if any, completely independent scientists. Almost all scientific research is carried out from within institutions. Those institutions not only make it possible for science to be done, they can also constrain the science that can be done and shape the purposes for which it is done, and they influence whether and how it is represented to others. These institutions are located in, and shaped by, the particular political-economic context as described above. Thus, for example, government expectations of returns from scientific research, as well as prevailing orientations toward education and public investment more generally, shape the institutions within which scientists work, such as universities or research institutes, and those institutions' operating environment.[12]

Moving from this high-level overview to a specific example, New Zealand provides a case of politically driven, "radical" and "abrupt" changes to science institutions over recent decades (Halliwell and Smith 2011). These changes included: reorganisation of a government department charged with nationally important scientific and industrial research (the Department of Scientific and Industrial Research or DSIR) into ten (now seven) commercially-focused Crown Research Institutes; the sudden and unusually comprehensive change from bulk funding of institutions to competitive funding of specific projects, producing one of the highest levels of funding contestability in the OECD (Organisation for Economic Co-operation and Development 2007; Davenport and Bibby 2007); repeated restructurings and reorganisations of government agencies responsible for science funding and policy; and introduction of individual assessment exercises and "performance-based research funding" for universities. In 1992, there was a dramatic shift from a bureaucratic and largely non-commercial system of government-funded science to a highly corporatized and commercial system. These changes have impacted upon the motivations for, messages within, and even possibility of associated outreach practices, both on an institutional and individual level.

In a recent survey conducted by the New Zealand Association of Scientists, forty percent of those responding answered "yes" to the question: Have you ever been prevented from making a public comment on a controversial issue by your management's policy, or by fear of losing research funding?[13] Comments included: "We are expressly prevented from making any comment to the public without prior approval. On contentious issues such as GMOs … we are not to make any comment at all under any circumstance. That role is now exclusively the mandate of management [of the CRI]." "When I was in a CRI, I had funding moved from me to another scientist after a visit from industry who were upset at the factual comments put out in a newspaper article by a scientist working in my research project." "Yes when I worked in NZ for a CRI, but not when I worked for DSIR or after I moved to a university." "I worked out with my manager and an acting CEO that it would be appropriate to represent a environmental NGO in giving evidence to a government regulatory body that would effectively have been public (and probably newsworthy) to ensure this NGO had access to some expert testimony on a high profile issue. The CEO returned from leave and quashed this testimony, to avoid having the CRI associated with the NGO." While those working in CRIs were more likely to answer "yes", university scientists have also been affected: "Yes, I have been fearful of making controversial public comment for fear it would jeopardise funding, which would result in job loss for others in my team, even if not for me."[14]

[12] This is not to say that recent developments have put an end to some golden age of independent science. As Pestre (Pestre 2003, p247) has pointed out, "for at least the last five centuries, knowledge—be it 'pure' or applied, elaborated in universities or in other places—has been of crucial interest to power". Over time, there have been a number of different "regimes of knowledge production", varying in terms of "where knowledge has been produced and with which particular interests in mind" (ibid.).

[13] The online survey received 384 responses. See http://www.scientists.org.nz/blog/2014/survey-on-the-proposed-code-of-public-engagement

[14] All comments from http://www.scientists.org.nz/blog/2014/survey-on-the-proposed-code-of-public-engagement

An understanding of institutional context is thus necessary for a more nuanced analysis of scientists' outreach and engagement practices. Both the type of institution and the overall operating context for science institutions are relevant. As with the politics of fields, these will differ from country to country. We therefore propose that a second approach to initiating reflexive practice would be scientists exploring their own understanding of the institutional context of their work, how this might influence their practices as scientists and scientist-communicators, and whether any of this can be communicated to the public.

Personal assumptions about science and the public

As noted above, scientists are typically trained to regard the scientific process as a unique route to the truth about the world. A third focus of reflexivity is therefore the scientist's own assumptions about the nature and value of science as well as about the various publics being addressed. What is the nature of the scientist's commitment to science and what are the implications of that for how the scientist communicates science? What are the scientists assumptions about and expectations for the public? What are seen as appropriate roles for the public in the outreach process? Is the public seen as dialogue-capable? Is science something about which there can or should be a dialogue (with the public)?

The answers to these are linked to assumptions about what counts as valid knowledge and how it comes to be accepted as valid. Do scientists have a monopoly of relevant knowledge? What kind of role for non-scientists is legitimate? What are the limits of that role? Similarly, what are the limits of science? In which societal arenas, or science-related issues, should science and scientists dominate, and in which should they play a more subordinate but contributory role (i.e, what is the legitimate jurisdiction of science, and when does science's claim to authority become 'scientistic'?)? And finally, how do these views shape the scientist's own goals for or methods of outreach?

This can be termed epistemological reflexivity. Calls for epistemological reflexivity feature in the literature on transdisciplinary research for sustainability because it is essential to enabling that research to move beyond an "unstructured pluralism" that construes "scientific reliability and social legitimacy as distinct requirements that have to be pursued in parallel and traded off against each other" (Popa et al. 2015) to one that "produces new knowledge by integrating different scientific and extra-scientific insights [and] … contribute[s] to both societal and scientific progress" (Jahn et al. 2012). We argue that it is also key to transforming public engagement with science, in part for scientists to be able to understand (and possibly participate in) the expectations held for engagement by some PES scholars and some publics. But it can be extremely challenging, as our literature experiment showed; indeed, much research on transdisciplinary research has found this area to be a key sticking point (Evans and Marvin 2006; Jahn et al. 2012; Popa et al. 2015).

We therefore propose that a third important facet of reflexivity involves scientists critically examining their personal assumptions about science and the public and how these assumptions shape their outreach efforts.

Barriers to achieving reflexivity

A number of barriers to achieving reflexivity have already been suggested. For example, the training scientists typically receive can make it difficult for them to conceptualise the non-scientist public as anything other than recipients for expert knowledge. As we have demonstrated, putting a stack of PES articles on their desks is unlikely to rectify this. The literature does not "speak for itself" to scientists.

Further, there are few professional incentives for scientists to invest additional time or energy into critical reflection about outreach, especially as the outreach activities themselves may already be regarded (by the scientists or their institutions) as a distraction from the "real work" of scientific research.[15] As a result, there is currently little scholarly analysis by scientists about their individual or collective outreach activities, and outreach efforts are rarely subject to scholarly scrutiny (Davies et al. 2009). In addition, there is very little analytical literature about outreach, or engagement, aimed at scientists, from which they can learn and to which they can contribute. The literature on outreach is instead dominated by short opinion pieces—typically urging scientists to do more outreach, or describing outreach activities (e.g. Leshner 2007; Reddy 2010; Gupta et al. 2013)—while the literature on engagement generally speaks past scientists rather than to them (as we discuss above). The lack of higher level interrogation of scientists' outreach (either by the scientists themselves or by social scientists directed at scientists) means that these activities tend to occur in a knowledge vacuum, are generally developed based on "what feels right" and personal or institutional motivations, and are neither informed by theory nor informing research in this field. For example, the assumption that greater scientific literacy correlates with greater public support for controversial science has been tested and rejected in STS and related fields (see, for example, Gross 1994; Irwin and Wynne 1996; House of Lords 2000; Bucchi and Neresini 2002), yet still prevails within the scientific community (Davies 2008; Winstanley 2012; and as demonstrated by the New Zealand National Science Panel 2013). Significant resources are therefore being invested in activities that are not well thought-out (because of a lack of understanding and

[15] This holds despite evidence demonstrating a positive relationship between academic achievement by scientists and their level of engagement with outreach activities (Jensen et al. 2008; Bentley and Kyvik 2011).

research on outreach), but are potentially having a significant impact on how science is represented to society.

When scientists do publish accounts or evaluations of their science-outreach work in peer-reviewed journals, it is generally in a publication focused on their specific science discipline, often in the form of a report or opinion piece rather than peer-reviewed research article, and only sometimes includes reference to relevant PES literature (e.g. Huffman et al. 2008; Salmon et al. 2011; Gupta et al. 2013; Davies and Glasser 2014). This further reduces the probability that theory and practice related to public engagement activities by scientists might inform each other. As a result, theoretical literature in this field is dominated by social science scholars, while outreach activities by scientists remain uninformed by this theory.

Even where a scientist has the desire and interest to evaluate his or her outreach activities, carry out a longer-term research project, and share these results in peer-reviewed fora related to PES and science communication, she or he is likely to experience several barriers in this process. While journals in these disciplines are entirely justified in rejecting articles that do not fulfil their research requirements or accepted methodologies, the net effect of this is that (a) the scientific community at large is not aware of opportunities to engage in scholarly dialogue about science communication and PES; and (b) there is little systematic study of, or data collection related to, outreach by scientists; with the result that (c) science outreach activities remain under-researched and uninformed by theory.

Strategies for fostering reflexivity

How might we overcome these barriers to reflexivity and encourage both "reflective practice" and "practical reflection" (Irwin 2014)? Below, we explore a range of strategies that could contribute to this goal.

Education and training

Traditional science education does not encourage the kind of reflexivity we have discussed here. Fostering such skills would ideally be incorporated into science education curricula through high school, undergraduate, and post-graduate studies. This is not, however, a new suggestion (see, eg, Sadler et al 2006; Hoover et al 2009; Barakat and Jiao 2010; Pohl et al. 2010) and is vulnerable to a number of problems, including school teachers feeling ill-prepared and lacking appropriate resources to tackle controversial issues; "crowded" science curricula at university; and the difficulties of instilling an orientation at odds with much of the rest of the curriculum.

Opportunities to explore these ideas do not stop with university, however. Indeed, such concepts and approaches may become more relevant and useful to the professional scientist who finds him- or herself engaging with the public on societally-relevant issues, something that is unlikely to occur to the student or early-career researcher (Salmon and Priestley 2015). The lack of attention to science communication in scientists' training has been acknowledged by a wide range of "science-media training" activities that are now available in many countries. In New Zealand, for example, the Science Media Centre offers a Science Media Savvy workshop that is designed to "increase confidence and enhance media skills in scientists and researchers" and "offers strategies to successfully navigate a range of media encounters, with take-home lessons that apply to equally to improving stakeholder engagement, funding applications, public talks and outreach" (Science Media Savvy). While these training activities tend to focus on public communication and media skills, they could also incorporate a basic introduction to consideration of the politics of field, institutional context, and personal assumptions within which the scientist operates.

Scientist engagement at science conferences

Science conferences also present an opportunity to explore these ideas in an environment that is familiar to scientists, and therefore less threatening or alienating than typical social science fora where such concepts are typically discussed. We explored this idea at two international science conferences [references deleted to maintain the integrity of the review process], through an oral and poster presentation, both of which were presented by "the scientist" authoring this paper. In both cases, we chose to use images to describe concepts, rather than words, cognizant that words are interpreted differently by each individual, possibly with negative connotations. One such figure, representing a "reflected scientist communicator", who looks in the mirror and sees an entirely positive reflection returned, made many conference delegates smile, laugh, and nod in recognition of the caricature of either themselves or a colleague. The use of humour, imagery, and introduction of the concepts by a member of the science community, appeared to be a successful combination for opening up this conversation in a non-threatening manner. These presentations have led directly to requests by major national science agencies for further conversations with their scientists about these ideas, despite the fact that far more established PES scholars live closer and have been operating in this field for longer than the presenting author. While this does not constitute evidence of the success of this approach, it is an example of a non-confrontational approach worth exploring to encourage initial steps in reflexive practice.

New metrics for evaluating outreach

Neresini and Bucchi (2010) provide a compelling argument for the need for new indicators for public engagement activities that indicate quality over quantity, identifying factors such

as an "intention to learn from experience and obtain relevant feedback" (p. 11) rather than delivery of activities that appear to be mostly a "goodwill exercise".

The establishment of such metrics, developed and endorsed by the PES community, would provide a tangible bridge between theory and practice—a tool that scientists and institutions could use to assess their outreach activities according to metrics and approaches that are grounded in PES theory. While such metrics alone would clearly not be enough to stimulate the kind of reflexive practice we advocate here, they could provide indicators around the goals of PES as well as mechanisms by which individuals would be encouraged to consider the different contexts and assumptions within which their outreach activities occur. Further, the development of such metrics would provide an opportunity to encourage institutional, as well as individual, reflexivity. An example of such an approach is demonstrated by Haywood and Besley's (2014) recommendations for indicators of success in participatory science (or "citizen science") programmes.

A second approach to validating "quality over quantity" would be to utilise a portfolio-based peer-review approach such as that recommended for the assessment of the creative, artistic, and design disciplines in tertiary institutions (Moore 2003). Thus, instead of measuring the success of a dialogue event by attendance numbers, "impact" or "calibre" might instead be demonstrated by a portfolio including references provided by external PES scholars, reports in the media, and anonymous participant feedback, as well as an evaluation or assessment exercise. The development of helpful metrics and feedback processes cannot, however, occur without prior reflection upon and clarity about what constitute appropriate goals for outreach.

Interdisciplinary and transdisciplinary research programmes and collaborations

Jahn et al (2012) argue that "bringing reflexivity into processes of knowledge production is both the claim and main purpose of the transdisciplinary research practice." Indeed, reflexivity is not only a goal of, but also a challenge for, transdisciplinary research (TR),[16] which attempts to integrate knowledge from both scientists and social scientists as well as from non-academic collaborators (Popa et al. 2015). A successful TR programme would almost certainly produce more reflexive scientist-communicators. However, TR is difficult, and reflexivity does not emerge automatically from it but rather must be deliberately cultivated (Jahn et al. 2012; Popa et al. 2015; Pohl 2010).

One recommendation to foster reflexivity might, therefore, be a requirement by funders for multi-disciplinary teams or even transdisciplinary research designs, which in turn requires a dedication among the researchers to confront exactly the kinds of misunderstandings and identity-challenges we discuss here. However, such a commitment to TR assumes the scientists involved are already convinced of the need to bring other "knowledges" into the mix. That is to say, they're likely to already be reflexive scientists, or on a journey towards reflexivity, as we have described it here.

We therefore take a step back in this recommendation and ask, instead, what processes and mechanisms might "open the door" for scientists to consider engaging in such TR programmes and collaborations? Looking again to ourselves for insight into "tipping points" that stimulated our interest in such conversations and collaborations, the scientist was strongly influenced by experiences on an art-science expedition related to climate change (Cape Farewell 2009), and the science writer by her involvement in a protest movement against nuclear weapons testing followed by employment by a nuclear science research institute (Priestley 2012 p.vi). Following these key experiences, collaborations by both with artists, educators, indigenous communities, NGOs, writers, historians, and policy-makers continued to foster this growing awareness of different perspectives on, assumptions about, and social and political influences on, science and scientists. These varied experiences and conversations were critical for developing the dialogue-capable state required for the process documented here.

A first step on the journey to reflexivity may thus be any of a wide range of scientist collaborations with non-scientists. Becoming aware of different perspectives in this way may be more likely to trigger an openness to further exploration than being initially confronted with the PES or STS literature. Examples include art-science collaborations, cross-disciplinary placements and secondments, multi-disciplinary conferences and symposia, citizen science programmes, and new opportunities offered through innovative digital technologies.[17] Our recommendation thus is to encourage the proliferation of such opportunities.

Opportunities for collaboration and publication

Based on our own experience, we believe one of the most promising strategies for promoting reflexivity is to create

[16] There are no standardised definitions in this area. Here we take interdisciplinary research to mean research involving multiple academic disciplines and requiring some degree of interaction (not simply separate, parallel tracks) among them. In contrast, transdisciplinary research not only involves multiple academic disciplines, including social as well as biophysical scientists, but also non-academic collaborators, and requires communication and even integration across different types of knowledge and epistemological approaches.

[17] For examples of such activities see: http://capefarewell.com/; http://www.hkw.de/en/programm/projekte/2014/anthropozaen_curriculum/anthropozaen_curriculum_1.php; http://blogs.plos.org/citizensci/2015/01/21/propose-join-citizen-science-hackfest-project/; http://www.macdiarmid.ac.nz/event/pounamu/ [all accessed February 23, 2015]

opportunities for collaboration between outreach practitioners and PES scholars in the production of a peer-reviewed academic publication. We imagined a scientist writing about outreach and being read, in draft, by a PES scholar who then queries some of the assumptions underlying the article, thus encouraging the scientist to make these explicit (to himself/herself and/or to the reader). Understandably, however, in the current peer-review process, there are few incentives or professional rewards for social scientists to either become mentors for these scientists, or to invest considerable time providing feedback as anonymous journal reviewers. Thus we suggest that a way forward may be to develop a publication model wherein this kind of peer-reviewer gets named credit on a publication (cf. Frontiers family of journals[18]), enhanced recognition in the peer-review process (cf. Lane 2013) or even becomes a co-author.

Unfortunately, scientists might also be actively discouraged to invest time in such publications due to the funding system or national research assessment exercises (e.g. Moed 2008; Northcott and Linacre 2010; Abramo et al. 2011). In order for this recommendation to be practical therefore, such assessment exercises would need to acknowledge, and even reward or encourage, cross-disciplinary collaboration.

This collaborative process should not be a one-way street. We also envision the process in reverse: PES scholars writing about engagement being read in draft by (or discussed with) an outreach practitioner. This is one road to "practical reflection" on the part of PES scholars. It would also make such articles more accessible to scientist-communicators by enabling the reviewer to identify areas that are likely to cause misunderstanding or mystification for those readers. In the process, the scientist reviewer would also engage more closely with the concepts and literatures therein, thus creating another mechanism for fostering reflexivity and stimulating dialogue on this topic. Indeed, to make the scholarly field of PES accessible to scientists, opportunities must be created in which they are able to contribute, engage, and inform the field, not just "listen to the experts" and read their work—anything less would be to implement another form of the deficit model, one in which the scientists are seen to be simply deficient of knowledge about PES with nothing to contribute to the field themselves.

If such opportunities for collaboration were created, there remain difficulties in finding an appropriate venue for publication of this research, such that it is readily accessible both by those involved in outreach "practice" and by those who study and critique such practice. Existing structures fail in this regard, so we argue again for a new model. With the development of online publishing and aggregation tools, several new publication models could be imagined in which scientists are able to publish and read within their own academic discipline, but these same articles are peer-reviewed by scholars in PES, and also collated through a mechanism that brings together both theory and practice in one place. By mentoring, and creating opportunities for scientists to explore their experiences through these varied fora, we would not only gain a wealth of data about currently undocumented activities, but also encourage greater engagement with research in this field by these scientist-communicators, and greater connection between theory and practice.

Recognising that the scientists involved in this process do not hold—or necessarily desire—the disciplinary expertise of PES scholars, alternative systems could also be developed that enable scientists to share their data and experiences in a research context without the expectation of needing to "compete" within the same literature and theoretical grounding. Such processes could also serve as a mechanism for "opening the door to reflexivity", as discussed above. Examples could include inclusion in a broader PES research project,[19] contribution to a database of outreach activities (cf. Metcalfe 2012) or documentation in a science publication (cf. Corbin and Katz 2012). This would also provide a mechanism for capture of a much wider range of data about science outreach in general, an issue identified by Bauer and Jensen (2011).

Disaggregation of the monolith of science

Social-science scholarship, especially that in PES and STS, could also play a greater role in fostering reflexivity. Scholarship in PES (and science communication) could do more to disaggregate the monolithic way in which science is sometimes represented in this literature, in particular by becoming more attentive to the politics of fields and institutional context of the scientists who are interacting with the public. Scholarship in STS could contribute by giving far more attention to the political-economic and institutional contexts of science. Indeed, a number of scholars have recently drawn attention to the neglect of political economy (e.g. Goven and Pavone 2015; Birch 2013; Lave, Mirowski, and Randalls 2010; Mirowski 2011; Tyfield 2012) and political institutions (e.g. Jasanoff and Kim 2009; Nowotny 2014) within STS. Tyfield (2012, p.160) has called STS "almost constitutionally allergic to issues of political economy", and Jasanoff and Kim (2009, p.120) observe that "[e]ven in highly political environments, STS research tends to be drawn to scientific and technological innovation as an end in itself, in preference to more complex relationships among knowledge, its applications, and power". Politics

[18] http://www.frontiersin.org/ [accessed February 23, 2015]

[19] As an example, the process of interviewing the geologists for this study, and sending them our final submitted text, triggered substantial conversations with two of them (separately) about these issues. One geologist later shared that the process had given him cause to reflect more on why he does outreach and whether there were any political motivations associated with his outreach efforts.

in STS is often studied as micro-level relations within the process of producing scientific knowledge or technological artefacts, quite divorced from institutional or structural contexts. As a result, we lack the detailed analyses of the politics of fields and institutions that could inform efforts at greater reflexivity by scientist-communicators.

Such research would do even more to promote reflexivity if it were carried out in collaboration with scientists. As suggested by the comments from the NZAS survey in Section 3.2 above, research in this area may well involve (and benefit from) interviews with scientists. Extending this involvement to encompass full collaboration (for example, working with a scientist on an auto-ethnography) or a peer-review process as described in the previous section would also benefit this kind of research.

Conclusion

Scientists and PES scholars have traditionally understood the concepts of "science communication" and "public engagement with science" in very different ways. The science community has traditionally been striving for public support of science and trust of scientists, whereas the PES community has been criticising both the public representation of science and the lack of public influence over what counts as appropriate development and use of science and technology. These differences may reflect deeper differences in the two groups' understandings of the nature of science and of the appropriate role of the wider public in relation to it. However, they may also reflect a lack of communication and/or mutual misunderstanding.

In order to "transform public engagement on new and emerging technologies", we argue that scientist-communicators and PES scholars must engage in a process of co-production of knowledge about outreach/engagement. We have shown that the PES literature will not "speak for itself" to scientists, but rather its terms and concepts must be interpreted and even negotiated with the scientists, and scientist-communicators, who are essential to putting many of the PES literature's proposals into practice. We have argued that the politics of the field, the institutional context, and personal assumptions are key areas about which the scientist-communicator will ideally be reflexive. We have noted barriers to the development of reflexivity and some strategies for overcoming them, particularly various forms of collaborative writing. The goal of this process is to mentor, encourage, and support a "reflexive scientist", one who is familiar with (and can contribute to) the critical PES literature; thoughtful and clear about the goal of his or her public engagement activities; and capable of critically analysing the relation between those activities and the politics of his or her own field, the relevant institutional context, and his or her own personal assumptions. Such reflexive practice, we argue, could make a major contribution to effective public engagement for sustainability.

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References

Abramo G, D'Angelo CA, Di Costa F (2011) National research assessment exercises: a comparison of peer review and bibliometrics rankings. Scientometrics 89:929–941

Anderson L (2008) Reflexivity. In: Thorpe R, Holt R (eds) The SAGE dictionary of qualitative management research. SAGE Publications Ltd., London, pp 184–186. doi:10.4135/9780857020109.n86

Atkinson-Grosjean J (2002) Science policy and university research: Canada and the USA, 1979–1999. Int J Technol Policy Manag 2: 102–124

Bäckstrand K (2003) Civic science for sustainability: reframing the role of experts, policy-makers and citizens in environmental governance. Glob Environ Politics 3:24–41. doi:10.1162/152638003322757916

Barakat N, Jiao H (2010) Proposed strategies for teaching ethics of nanotechnology. Nanoethics 4:221–228

Bauer MW, Jensen P (2011) The mobilization of scientists for public engagement. Public Underst Sci 20:3–11. doi:10.1177/0963662510394457

Bauer MW, Allum N, Miller S (2007) What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. Public Underst Sci 16:79–95

Bentley P, Kyvik S (2011) Academic staff and public communication: a survey of popular science publishing across 13 countries. Public Underst Sci 20:48–63. doi:10.1177/0963662510384461

Besley JC, Nisbet M (2013) How scientists view the public, the media and the political process. Public Underst Sci 22(6):644–659

Besley JC, Oh SH, Nisbet M (2012) Predicting scientists' participation in public life. Public Underst Sci 22(8):971–987

Birch K (2013) The political economy of technoscience: an emerging research agenda. Spontaneous Gener: J Hist Philos Sci 7:49–61. doi:10.4245/sponge.v7i1.19556

Blumenthal D (2003) Academic–industrial relationships in the life sciences. N Engl J Med 349:2452–2459. doi:10.1056/NEJMhpr035460

Bracken LJ, Oughton EA (2006) "What do you mean?" The importance of language in developing interdisciplinary research. Trans Inst Br Geogr 31:371–382. doi:10.1111/j.1475-5661.2006.00218.x

Brown MB (2009) Science in democracy: Expertise, institutions, and representation. MIT Press

Bruce A, Lyall C, Tait J, Williams R (2004) Interdisciplinary integration in Europe: the case of the fifth framework programme. Futures 36: 457–470. doi:10.1016/j.futures.2003.10.003

Bucchi M, Neresini F (2002) Biotech remains unloved by the more informed. Nature 416:261–261

Cape Farewell (2009) Andes Expedition. In: Cape Farewell. http://capefarewell.com/2009.html. Accessed 1 Jun 2015

Corbin JD, Katz ME (2012) Effective strategies to counter campus presentations on climate denial. EOS Trans Am Geophys Union 93: 252–253. doi:10.1029/2012EO270007

Crettaz von Roten F (2011) Gender differences in scientists' public outreach and engagement activities. Sci Commun 33:52–75. doi:10.1177/1075547010378658

Davenport S, Bibby D (2007) Contestability and contested stability: the life and times of CSIRO's New Zealand cousins, the crown research institutes. Innov Manag Policy Pract 9:181–191. doi:10.5172/impp.2007.9.2.181

Davies SR (2008) Constructing communication talking to scientists about talking to the public. Sci Commun 29:413–434

Davies SR (2013) Constituting public engagement: meanings and genealogies of pest in two u.k. studies. Sci Commun. doi:10.1177/1075547013478203

Davies B, Glasser NF (2014) Analysis of www.AntarcticGlaciers.org as a tool for online science communication. J Glaciol 60:399–406. doi:10.3189/2014JoG13J194

Davies S, McCallie E, Simonsson E et al (2009) Discussing dialogue: perspectives on the value of science dialogue events that do not inform policy. Public Underst Sci 18:338–353

Dixon J, Sharp L (2007) Collaborative research in sustainable water management: issues of interdisciplinarity. Interdiscip Sci Rev 32:221–232. doi:10.1179/030801807X183650

Dunwoody S, Brossard D, Dudo A (2009) Socialization or rewards? Predicting US. Scientist-media interactions. J Mass Commun Q 86:299–314. doi:10.1177/107769900908600203

Einsiedel EF, Jelsøe E, Breck T (2001) Publics at the technology table: the consensus conference in Denmark, Canada, and Australia. Public Underst Sci 10:83–98. doi:10.1088/0963-6625/10/1/306

Evans R, Marvin S (2006) Researching the sustainable city: three modes of interdisciplinarity. Environ Plan A 38:1009–1028. doi:10.1068/a37317

Falchetti E, Caravita S, Sperduti A (2007) What do laypersons want to know from scientists? An analysis of a dialogue between scientists and laypersons on the web site Scienzaonline. Public Underst Sci 16:489–506

Felt U, Fochler M (2010) Machineries for making publics: inscribing and de-scribing publics in public engagement. Minerva 48:219–238. doi:10.1007/s11024-010-9155-x

Fisher E, Mahajan RL, Mitcham C (2006) Midstream modulation of technology: governance from within. Bull Sci Technol Soc 26:485–496. doi:10.1177/0270467606295402

Gibbons M, Limoges C, Nowotny H, et al. (1994) The new production of knowledge: The dynamics of science and research in contemporary societies. Sage

Goven J (2003) Deploying the consensus conference in New Zealand: democracy and de-problematization. Public Underst Sci 12:423–440

Goven J (2006a) Dialogue, governance, and biotechnology: acknowledging the context of the conversation, Integrated Assessment 6:2. http://journals.sfu.ca/int_assess/index.php/iaj/article/view/160

Goven J (2006b) Processes of inclusion, cultures of calculation, structures of power scientific citizenship and the royal commission on genetic modification. Sci Technol Hum Values 31:565–598. doi:10.1177/0162243906289612

Goven J (2008) Assessing genetic testing: who are the "lay experts"? Health Policy 85:1–18. doi:10.1016/j.healthpol.2007.06.004

Goven J, Pavone V (2015) The bioeconomy as political project a polanyian analysis. Sci Technol Hum Values 40:302–337. doi:10.1177/0162243914552133

Gross AG (1994) The roles of rhetoric in the public understanding of science. Public Underst Sci 3:3–23

Gupta N, Hamilton K, Chamot J (2013) Conveying cutting-edge discoveries to nonscientists: effective communication with media. JOM 65:835–839. doi:10.1007/s11837-013-0617-0

Hagendijk RP (2004) The public understanding of science and public participation in regulated worlds. Minerva 42:41–59

Halliwell J, Smith W (2011) Paradox and potential: trends in science policy and practice in Canada and New Zealand. Prometheus 29:373–391. doi:10.1080/08109028.2011.641385

Haywood BK, Besley JC (2014) Education, outreach, and inclusive engagement: towards integrated indicators of successful program outcomes in participatory science. Public Underst Sci 23:92–106

Hoover E, Brown P, Averick M et al (2009) Teaching small and thinking large: effects of including social and ethical implications in an interdisciplinary nanotechnology course. J Nano Ed (Print) 1:86

House of Lords (2000) Science and society. 3rd Report of the Select Committee on Science and Technology. The Stationery Office, Parliament, London

Huffman LT, Levy R, Lacy L et al (2008) ANDRILL's education and outreach programme 2005–2008: MIS and SMS project activities during the 4th IPY. Terra Antarct 15:221–235

Irwin A (2001) Constructing the scientific citizen: science and democracy in the biosciences. Public Underst Sci 10:1–18

Irwin A (2014) From deficit to democracy (re-visited). Public Underst Sci 23:71–76. doi:10.1177/0963662513510646

Irwin A, Wynne B (1996) Misunderstanding science?: The public reconstruction of science and technology. Cambridge University Press

Jahn T, Bergmann M, Keil F (2012) Transdisciplinarity: between mainstreaming and marginalization. Ecol Econ 79:1–10. doi:10.1016/j.ecolecon.2012.04.017

Jasanoff S (2003) Technologies of humility: citizen participation in governing science. Minerva 41:223–244

Jasanoff S (2004) Ordering knowledge, ordering society. In: Jasanoff S (ed) States of knowledge: the co-production of science and social order. Routledge, London and New York, pp 13–45

Jasanoff S (2014) A mirror for science. Public Underst Sci 23:21–26. doi:10.1177/0963662513505509

Jasanoff S, Kim S-H (2009) Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea. Minerva 47:119–146. doi:10.1007/s11024-009-9124-4

Jensen P (2011) A statistical picture of popularization activities and their evolutions in France. Public Underst Sci 20:26–36

Jensen E, Buckley N (2012) Why people attend science festivals: interests, motivations and self-reported benefits of public engagement with research. Publ Underst Sci

Jensen P, Rouquier J-B, Kreimer P, Croissant Y (2008) Scientists who engage with society perform better academically. Sci Public Policy 35:527–541

Kitcher P (2011) Science in a democratic society. Poznan Stud Philos Sci Human 101:95–112

Kleinman DL (2003) Impure cultures: university biology and the world of commerce. Univ of Wisconsin Press

Kreimer P, Levin L, Jensen P (2011) Popularization by Argentine researchers: the activities and motivations of CONICET scientists. Public Underst Sci 20:37–47

Kuntz M (2012) The postmodern assault on science. EMBO Rep 13:885–889. doi:10.1038/embor.2012.130

Lane SN (2013) Acting, predicting and intervening in a socio-hydrological world. Hydrol Earth Syst Sci Discuss 10:C6079–C6083. http://www.hydrol-earth-syst-sci-discuss.net/10/C6079/2013/

Lave R, Mirowski P, Randalls S (2010) Introduction: STS and neoliberal science. Soc Stud Sci 40(5):659–675

Lehr JL, McCallie E, Davies SR et al (2007) The value of "dialogue events" as sites of learning: an exploration of research and evaluation frameworks. Int J Sci Educ 29:1467–1487. doi:10.1080/09500690701494092

Leshner AI (2007) Editorial: outreach training needed. Science 315:161

Lezaun J, Soneryd L (2007) Consulting citizens: technologies of elicitation and the mobility of publics. Public Underst Sci 16:279–297

Lin S-J (2013) Perceived impact of a documentary film: an investigation of the first-person effect and its implications for environmental issues. Sci Commun 35:708–733. doi:10.1177/1075547013478204

Lowe P, Phillipson J, Wilkinson K (2013) Why social scientists should engage with natural scientists. Contemp Soc Sci 8:1–16. doi:10.1080/21582041.2013.769617

Mayhew MA, Hall MK (2012) Science communication in a café scientifique for high school teens. Sci Commun 34:546–554. doi:10.1177/1075547012444790

Metcalfe JA, Kristin, Shore, J (2012) National audit of Australian science engagement activities
Michael M (2009) Publics performing publics: of PiGs, PiPs and politics. Public Underst Sci 18:617–631. doi:10.1177/0963662508098581
Mirowski P (2011) Science-mart. Harvard University Press
Mobjörk M (2010) Consulting versus participatory transdisciplinarity: a refined classification of transdisciplinary research. Futures 42:866–873. doi:10.1016/j.futures.2010.03.003
Moed HF (2008) UK Research assessment exercises: informed judgments on research quality or quantity? Scientometrics 74:153–161
Moore GT (2003) Recommendations for the parity of creative, artistic, design and professional work with traditional forms of research and scholarship; in C. Newton (Ed.), Design + Research: Project Based Research in Architecture (Melbourne) Available at:http://sydney.edu.au/architecture/documents/staff/garymoore/113.pdf [retrieved February 22, 2015]
National Science Panel (2013) A challenge for New Zealand's leadership - the "Science and Society" challenge. Report of the national science challenges panel. 33–35
Neresini F, Bucchi M (2010) Which indicators for the new public engagement activities? An exploratory study of European research institutions. Public Understanding of Science 0963662510388363
Northcott D, Linacre S (2010) Producing spaces for academic discourse: the impact of research assessment exercises and journal quality rankings. Aust Account Rev 20:38–54
Nowotny H (2000) Transgressive competence: the narrative of expertise. Eur J Soc Theory 3:5–21. doi:10.1177/136843100003001001
Nowotny H (2014) Engaging with the political imaginaries of science: Near misses and future targets. Public Underst Sci 23:16–20. doi:10.1177/0963662513476220
Oreskes N, Conway EM (2010) Merchants of doubt: how a handful of scientists obscured the truth on issues from tobacco smoke to global warming. Bloomsbury Publishing
Organisation for Economic Co-operation and Development (2007) New-Zealand. OECD reviews of innovation policy, Paris
Osborne J, Dillon J (2007) Research on learning in informal contexts: advancing the field? Int J Sci Educ 29:1441–1445. doi:10.1080/09500690701491122
Pestre D (2003) Regimes of knowledge production in society: towards a more political and social reading. Minerva 41:245–261. doi:10.1023/A:1025553311412
Petts J, Owens S, Bulkeley H (2008) Crossing boundaries: interdisciplinarity in the context of urban environments. Geoforum 39:593–601. doi:10.1016/j.geoforum.2006.02.008
Pohl C, Rist S, Zimmermann A et al (2010) Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. Sci Public Policy 37: 267–281
Poliakoff E, Webb TL (2007) What factors predict scientists' intentions to participate in public engagement of science activities? Sci Commun 29:242–263. doi:10.1177/1075547007308009
Popa F, Guillermin M, Dedeurwaerdere T (2015) A pragmatist approach to transdisciplinarity in sustainability research: from complex systems theory to reflexive science. Futures 65:45–56. doi:10.1016/j.futures.2014.02.002
Powell M, Colin M, Lee Kleinman D et al (2011) Imagining ordinary citizens? Conceptualized and actual participants for deliberations on emerging technologies. Sci Cult 20:37–70. doi:10.1080/09505430903567741
Priestley R (2006) Ernest Marsden's nuclear New Zealand: from nuclear reactors to nuclear disarmament. 139: 23–38
Priestley RK (2010) Nuclear New Zealand: New Zealand's nuclear and radiation history to 1987; Ph.D., University of Canterbury, 2010
Priestley R (2012) Mad on Radium: New Zealand in the atomic age. Auckland University Press, Auckland
Reddy CM (2010) Dude, you are speaking romulan. EOS Trans Am Geophys Union 91:384–384. doi:10.1029/2010EO420005
Robbins PT (2007) The reflexive engineer: perceptions of integrated development. J Int Dev 19:99–110. doi:10.1002/jid.1351
Sadler TD, Amirshokoohi A, Kazempour M, Allspaw KM (2006) Socioscience and ethics in science classrooms: teacher perspectives and strategies. J Res Sci Teach 43:353–376
Salmon RA (2013a) Is climate science gendered? A reflection by a female "climate scientist.". Womens Stud J 27:49–55
Salmon RA (2013b) New Zealand ICEFEST 2012 science & education programme summary and evaluation, report prepared for Christchurch city council
Salmon RA, Priestley RK (2015) A future for public engagement with science in New Zealand. J R Soc N Z 45: 2: 1–7. doi:10.1080/03036758.2015.1023320
Salmon RA, Carlson DJ, Zicus S et al (2011) Education, outreach and communication during the International polar year 2007–2008: stimulating a global polar community. Polar J 1:265–285. doi:10.1080/2154896X.2011.626629
Science Media Savvy. Available at: <http://www.sciencemediacentre.co.nz/media-savvy-workshops/>. [Accessed 23 February 2015]
Sievanen L, Campbell LM, Leslie HM (2012) Challenges to interdisciplinary research in ecosystem-based management. Conserv Biol 26: 315–323. doi:10.1111/j.1523-1739.2011.01808.x
Stilgoe J, Lock SJ, Wilsdon J (2014) Why should we promote public engagement with science? Public Underst Sci 23:4–15. doi:10.1177/0963662513518154
Sturgis P (2014) On the limits of public engagement for the governance of emerging technologies. Public Underst Sci 23:38–42. doi:10.1177/0963662512468657
The Royal Society (2006) Survey of factors affecting science communication by scientists and engineers. Available at: https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2006/1111111395.pdf [retrieved February 22, 2015]
Thorpe C, Gregory J (2010) Producing the post-Fordist public: the political economy of public engagement with science. Sci Cult 19:273–301
Torres-Albero C, Fernández-Esquinas M, Rey-Rocha J, Martín-Sempere MJ (2011) Dissemination practices in the Spanish research system: scientists trapped in a golden cage. Public Underst Sci 20:12–25. doi:10.1177/0963662510382361
Tyfield D (2012) A cultural political economy of research and innovation in an age of crisis. Minerva 50:149–167. doi:10.1007/s11024-012-9201-y
Varner J (2014) Scientific outreach: toward effective public engagement with biological science. Bioscience 64:333–340. doi:10.1093/biosci/biu021
Weigold MF (2001) Communicating science a review of the literature. Sci Commun 23:164–193
Wilkinson C, Bultitude K, Dawson E (2011) "Oh yes, robots! People like robots; the robot people should do something": perspectives and prospects in public engagement with robotics. Sci Commun 33: 367–397
Winner L (2010) The whale and the reactor: A search for limits in an age of high technology. University of Chicago Press
Winstanley AH, Maria (2012) Research into the views and preferences of scientists and their employers towards non-peer communication. Research provided for the Ministry for Science and Innovation
Wynne B (1993) Public uptake of science: a case for institutional reflexivity. Public Underst Sci 2:321–337
Wynne B (2006) Public engagement as a means of restoring public trust in science—hitting the notes, but missing the music? Public Health Genom 9:211–220
Wynne B (2014) Further disorientation in the hall of mirrors. Public Underst Sci 23:60–70. doi:10.1177/0963662513505397