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Contemporary high-profile scientists and their interactions with the community

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ABSTRACT

This article presents a case study of 10 high-profile Australian research scientists. These scientists are highly committed to engaging with the public. They interact with a wide range of groups in the community, including the traditional media. They are aware that they are seen as representatives of science at a time when the authority of science and scientists is threatened in Australia by controversy around issues such as climate change and vaccination. Through their experiences of interacting with non-scientists, they have developed views about qualities, characteristics and knowledge that contribute to, or inhibit, positive interactions between scientists and non-scientists. Their experiences and insights highlight aspects of contemporary science that are not generally acknowledged in science curricula.

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Introduction

Relationships between science and the society in which science is conducted evolve. One important and interesting aspect of contemporary science is that scientists increasingly are expected to engage with a variety of different groups in the public domain about their science (e.g. Collins & Bodmer, 1986; Trench & Miller, 2012). Some of the research scientists who respond to these expectations may, by choice or by circumstance, develop a high public profile.

Previous studies done by researchers with an interest in science education into the ways that scientists interact with the public have tended to focus on the ways the public see these interactions (Feinstein, 2011; Layton, Jenkins, Macgill, & Davey, 1993). The researchers have tended to consider the implications of their research for a school science curriculum that is useful in the sense that it equips future science 'outsiders' (Feinstein, 2011) to handle life in scientifically and technologically complex societies.

The research reported in this article is concerned with the complementary perspective of research scientists on their interactions with various community groups. The underpinning motivation in seeking their perspective on these interactions is to consider the extent to which science education in schools and universities might be said to prepare a future

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research scientist as both a citizen and an expert for the public engagement that will be expected as an aspect of their future work (Smith, 2011).

We report on interviews with 10 high-profile research scientists from varied fields of science and locations in Australia. Specifically, we report how the high-profile research scientists perceive the qualities, characteristics and knowledge that will support successful interactions between scientists and non-scientists, and the obstacles that inhibit successful interactions between scientists and non-scientists.

The high-profile scientists have significant contact with a wide range of groups in society. One indicator of the high profile of these research scientists is that they are often asked to comment or give advice on current issues involving science, even if that science is outside the specialist field of the scientist. The most significant issue involving science in Australia when these data were produced was the existence of possible solutions to human-induced climate change; an acrimonious and divisive debate on this issue was prominent in newspapers and other print media, as well as television and radio. Another science-related issue current at the time was vaccination.

The findings of this study provide fresh insights into aspects of contemporary research science that generally are not acknowledged in contemporary science curricula, and that have the potential to further broaden the accounts of science provided in schools and universities (Smith, Mulhall, Gunstone, & Hart, 2015a).

The background to this study: scientists' communication and engagement with the public

Studies of the relationships between contemporary science and society show that society plays an increasingly influential role in shaping science (Funtowicz & Ravetz, 2003; Jasanoff, 2003; Nowotny, 2003). Science itself has recognised this changing relationship. This is manifested, as indicated earlier, in an explicit expectation that scientists should engage in public communication. For example, a report released by the Royal Society concluded that each scientist should 'learn to communicate with the public, be willing to do so, and consider it your duty to do so' (cited in Collins & Bodmer, 1986, p. 102). More recently, a report that reviewed the controversy surrounding hacked emails from the Climate Research Unit at the University of East Anglia in the U.K., asserted scientists should ensure they communicate with the public in ways that the public comprehends, and without making claims that are excessive (Russell, Boulton, Clarke, Eyton, & Norton, 2010, p. 40). Trench and Miller (2012) observe that across Europe communicating with the public is 'being inscribed into the norms and operations of the institutions where scientists work' (p. 723).

A significant proportion of scientists do undertake some public communication or other engagement. Large-scale studies in the U.K. and the U.S.A. suggest that over a half of scientists engage with non-scientists (MORI, 2001; Pew Research Center for the People & the Press, 2009); the aforementioned U.K. study also found some 84% had received no training in this public engagement. However, despite the expectation that scientists communicate with the public, there is little research on scientists' actual experience in undertaking such engagement. Instead, research on scientists' interactions with non-scientists in society has tended to focus on scientists' views about the public's science understanding. It is worth noting that this research has generally not explored

the basis of scientists' views, and whether they are grounded in experience, published research, or 'folk theory' (Landström, Hauxwell-Baldwin, Lorenzoni, & Rogers-Hayden, 2015).

In general, studies seem to indicate that scientists hold the view that the public's understanding of science is broadly inadequate (Burchell, 2007; Cook, Pieri, & Robbins, 2004; Frewer et al., 2003). This so-called 'deficit' view is manifested in the common belief amongst scientists that the goal of communication with the public is to provide information to correct (mis-) understandings on the part of the public (Davies, 2008; Horst, 2013; Yearley, 2000). In particular, scientists regard the public as having inadequate knowledge about science content and also about the provisional nature of scientific knowledge (Russell et al., 2010), including of scientific uncertainty (Frewer et al., 2003; Landström et al., 2015). Perceptions such as these appear to impact on scientists' views about, and approaches to, engaging with the public. For example, a study of food scientists by Frewer et al. (2003) found they were reluctant to provide the public with information about uncertainty associated with risk analysis of food. These scientists felt the provision of such information was likely to increase mistrust in science as the public did not understand scientific uncertainty.

Other work suggests that scientists see communication with the public as difficult or dangerous, requiring the cautious presentation of information to avoid misunderstanding or misuse by the public (Davies, 2008). Furthermore, scientists whose work concerns areas that are controversial may feel pressure to counteract criticism from sceptics; these scientists may adopt an approach that is guarded and emphasises the certain, and they may avoid areas that might be challenged (Tosse, 2013). Scientists tend to partly blame the public's (mis-) understanding of science on the media (Besley & Nisbet, 2013). Scientists may regard journalists as having a poor understanding of science themselves, and their coverage of news may be seen as emphasising the interests of minority groups rather than the views of scientific experts (Landström et al., 2015; Tosse, 2013).

By contrast with the views of scientists reported above, science communication researchers and practitioners increasingly envision science communication as a form of dialogue between scientists and non-scientists (Besley, Dudo, & Storksdieck, 2015). Science communication experts emphasise the importance of scientists listening to, and showing care and concern towards an audience, as well as paying attention to framing scientific messages so they resonate with an audience's values and predispositions (Davis & Russ, 2015). However, despite these emphases, a recent large scale study of American scientists' views about science communication training found they most valued training that would improve their ability to explain science phenomena and be seen as credible and trustworthy representatives of science (Besley et al., 2015). The scientists in the study placed less value on goals associated with being seen as caring and with framing messages according to the audience, possibly seeing such an approach as manipulative. In addition, a review of science communication training initiatives in Europe found there was a tendency to emphasise scientists' capacity to disseminate information over being able to engage in dialogue with non-scientists (Trench & Miller, 2012). Overall it seems that a move away from the traditional science communication goals of educating a deficient public is slow. Scientists and those who provide their training, for the most part, see communication and engagement with non-scientists in terms of providing information in order to educate a public whose understanding of and about science is poor.

However, it appears that actual experience interacting with non-scientists may impact positively on scientists' views about non-scientists. Some studies suggest that scientists who have experience communicating with the public tend to have more complex and nuanced views about public understanding of science (Besley & Nisbet, 2013; Blok, Jensen, & Kaltoft, 2008; Mogendorff, te Molder, Gremmen, & van Woerkum, 2012). Similarly, research exploring the views of experts from a range of disciplinary backgrounds found that those with lengthy experience of collaborating with policy-makers were more likely to regard them as having a good understanding of scientific uncertainty (Landström et al., 2015).

Arguably, then, research scientists who have considerable experience interacting with the broader community might reasonably be supposed to have developed valuable insights about productively engaging with non-scientists. Despite this, little of the extant literature attends to the actual experiences of these research scientists and the views they have formed on this basis. In the study that is the focus of this article, we explore the experiences and views of high-profile research scientists and seek to understand the skills, knowledge and characteristics they consider assist in such interactions.

The study

In this article we report on the data from 10 high-profile research scientists who were part of a larger qualitative research project that involved 36 Australian research scientists whose work entails regular interaction with groups in the community. The high-profile research scientists were specifically invited to join the research project. They were chosen for inclusion in the study as a particular group because they were known to have chosen to engage with a wide range of groups in society in addition to developing highly successful scientific careers. Because of the high public profiles of our participants we have been carefully unspecific about the areas of science in which they work so that the identity of each participant is protected. All names are pseudonyms.

All scientists participated in one-on-one semi-structured interviews conducted by one of the authors. The interviews lasted from 90 to 120 minutes and explored the different kinds of groups with whom the participant interacted as part of his or her work as a research scientist; the capacities or abilities needed to productively interact with these different groups, and how these capacities or abilities developed; the participant's views on the need for scientists in general to engage with the public about their work, and the participant's own experience of such engagement; the participant's views on the competencies, attitudes and skills required by (i) scientists and (ii) the public for productive interactions between scientists and the public; and the participant's experience of learning science at school. Further details of the interviews are given in Smith and Mulhall (2015). All interviews were recorded and fully transcribed.

These data were examined using interpretive phenomenological analysis (Smith & Osborn, 2008). A master list of the most common themes (Smith, 1995) was generated and refined after checking between authors for accuracy and consistency of interpretation of data. An additional list was also compiled to show the groups with whom the high-profile research scientists interact as part of their work.

The research questions that guided this case study were:

From the perspectives of the high-profile scientists:

(1) What qualities, characteristics and knowledge support successful interaction between scientists and non-scientists?
(2) What obstacles inhibit successful interaction between scientists and non-scientists?

The findings are now provided.

Findings

All the high-profile scientists engage with both scientific and non-scientific groups in the community. These high-profile scientists continue to do research science and many of them teach in universities either as faculty or as adjunct professors. In addition, taken as a group, they work with the public in a wide variety of ways: they attend Town Hall meetings; they give advice to a range of people, including politicians and public servants; they participate in meetings of local special interest groups; they speak about science and science related issues in the traditional print and broadcast media and they address students in primary and secondary schools.

Table 1 illustrates the wide variety and type of non-scientific groups with whom the high-profile scientists reported on in this article interact. When interacting with these groups, the high-profile scientists cannot assume the people with whom they interact have a scientific background, although some may. For that reason in the following analysis of the interviews we refer to the individuals in these groups as 'non-scientists'.

Some information about these scientists has been presented elsewhere (Smith, Mulhall, Gunstone, & Hart, 2015b) and we summarise it here as background. In general, the high-profile scientists have received little training to assist them in these interactions with different groups and they have learned how to do so productively through a process of trial and error and reflection upon experience. Their motivation for engaging with these groups is underpinned by a commitment to sharing knowledge for the benefit of society. Also, although only some of the high-profile scientists conduct research relevant to climate change, all indicated that the climate change controversy that was current in Australia at the time of the interviews impacted on their interactions with non-scientists, and they felt they were seen and judged as representatives of science generally.

Table 1. The various non-scientific groups with whom the high-profile scientists interact.

Groups (not including university students)	Scientist's name									
	Maurice	Dean	Kim	Ivan	Prue	Padraic	Ray	Sam	Lara	Alison
Community groups/NGOs/special interest groups	X	X	X	X		X			X	X
Politicians/political party	X	X	X	X	X	X	X	X	X	
Media	X	X	X	X	X	X	X	X	X	X
Senior policy-makers/government officials		X	X	X	X		X	X	X	X
Lawyers/engineers/architects	X		X	X						
Schools		X	X	X				X		X
Land/site managers			X	X						
Business/industry groups	X	X			X	X	X	X		
Social scientists	X	X								
Indigenous communities				X				X		
General public (e.g. town hall meetings, writing for lay audience)	X			X	X	X		X	X	X
Funding agencies/bodies					X	X				
University officials					X			X		

In the following analysis we show that the high-profile scientists felt some of the features they saw as hallmarks of a being good scientist and/or doing good science supported a scientist's productive engagement with non-scientists. However, these hallmarks of being a good scientist were not always adequate and the scientists identified additional skills that a scientist needs when interacting with some groups of non-scientists. A key skill here was the ability to express scientific ideas in a variety of ways so that they might be understood by non-scientists who have a wide range of backgrounds and interests.

We elaborate these ideas below. The discussion is organised under headings that reflect the research questions and sub-headings that represent major themes identified in the interviews with the high-profile scientists.

Qualities, characteristics and knowledge that support successful interaction between scientists and non-scientists

As noted above, the high-profile scientists reported that some characteristics, qualities and knowledge that they associated with being a good scientist were also useful in their interactions with non-scientists. Each of these is now considered.

Having an appreciation of the provisional nature of science and being open-minded assists scientists in their interactions with non-scientists. The high-profile research scientists felt that good scientists understand that science is provisional in the sense that science ideas can be temporary and conditional, and subject to changes as new evidence unfolds. Ray noted:

> … you, in fact, could say that the hallmark of science ought to be that the first thing you admit is … you can never fully know the answer. (Ray)

Understanding that science is provisional was intertwined with being open to the possibility that initial ideas may need to be changed. As Prue observed,

> … you have to be quite open to the possibility that – the formal way of saying it is your hypothesis – but it's never really quite so concrete as that – but whatever you came in with thinking that maybe this is the case, you actually have to be willing … to allow the evidence to indicate that that might be wrong. (Prue)

Similarly, Alison commented that scientists require 'the ability to chuck it all away and start again … because often what we pursue is just plain wrong' while Sam stated they needed to be able to hold 'multiple, perhaps competing views of the same thing in your brain simultaneously, and [be] able to weigh that up against a particular conclusion'. Both abilities present challenges for the individual scientist and require, as Prue noted, 'a special relationship with your ego'.

Having an appreciation of the provisional nature of science and being open-minded were seen as important not only when scientists are undertaking scientific work but also when they engage with non-scientists. These attributes enable scientists to be receptive to new ideas and be comfortable explaining changes in their thinking. Kim noted that scientists who 'defend … to the death' ideas that are more based on what they wanted to believe than on good evidence tend to struggle in their interactions with non-scientists. Ivan provided an exemplar of how a scientist might explain changes in scientific conclusions to non-scientists. He recounted an instance where, in his role as an expert witness

during a lengthy trial, he changed his mind. His change of mind was challenged by the prosecution:

> [The prosecutor] said, 'Well you, you've changed your view [over some] years! … it means … what you said before is all lies!' I said, 'That might be *your* perspective, but as a scientist, when I find new information, I am morally … and ethically obliged to review my previous findings, and if the data indicates that I was wrong in my deductions before, then I *must* change them, and must express that.' And I said, 'I am aware that my changed understandings are not to your liking, but I can only tell the truth,' and I said, 'and this is part of the power of the scientific method, and because when you're dealing with data, there's always interpretation placed on it, and you check that out against models and see if it's consistent, and if it is, then that's what you [deem] at the time'. (Ivan's emphases)

At the conclusion of providing his expert opinion, the judge commended him for the clarity of his explanation to the jury, a commendation that Ivan interpreted to be 'a *tick* … in terms of science communication' (Ivan's emphasis).

Understanding and acknowledging the limitations of science and their expertise helps scientists to engage productively with non-scientists. The temptation for scientists to make unsubstantiated pronouncements or to discuss matters beyond their expertise during interactions with the public was raised by the high-profile scientists. As Sam noted, it was easy for a scientist to think 'we're … experts on everything under the sun' and to think that 'to get any traction, you've got to make black and white statements'. Instead, as Ray observed, scientists should not '[go] in as the world expert in X, Y, Z, but as someone who's learning'. Importantly, this means being open about the limitations of science. For example, Ray felt that responses to climate change sceptics, should be:

> … here's the certain, here's the bit uncertain, and here's the haven't got a clue. That is far more honest [than ridicule] and likely to have a far more useful result. (Ray)

Broadly, the high-profile scientists agreed with the view expressed by Sam, '[I]t's the responsibility of scientists to try to reveal to the public how it is we think, and how it is we go about coming to a conclusion, and the bounds we can put on that.'

Obstacles that inhibit successful interaction between scientists and non-scientists

As we discussed above, the high-profile scientists indicated that the some of the qualities and knowledge they associated with good scientific practice helped to support scientists' successful interactions with various sections of the public. However, there were situations in which these skills and attitudes proved insufficient. One particular subgroup that our participants mentioned specifically in this context was the traditional broadcast and print media. This may be a particular consequence of the significantly high coverage being given to climate change in Australia at the time and the presence of influential media figures who were clear climate-change deniers; nevertheless, we report it here to convey some sense of the significant effect it had on the professional lives of these scientists and the challenges scientists may face when trying to make their science accessible to the broader public.

Scientists need to be able to explain scientific ideas in language non-scientists can understand. Our participants expressed a view that scientists need to know how to adapt their

scientific knowledge so they can discuss and explain complex scientific ideas to non-scientists as well as to their peers. As Maurice said, 'You [i.e. a scientist] can't talk to the public in the same way that you can to fellow scientists'. Yet, developing explanations that are accessible to the public can be difficult.

For the high-profile scientists, learning to explain scientific ideas in ways that non-scientists understood seemed to be ongoing. The process involved trial and error about which explanations could be understood by different groups of non-scientists, and included developing anecdotes, analogies and metaphors that the latter could relate to. Ivan, a chemist, reported that indigenous groups 'understood very clearly' an analogy he developed about high temperature processes that promote the acceptance of electrons by metallic ions in order to convert minerals to metals: 'I said, "It's like attaching a woomera to a spear and you can make it go ten times faster and further with great accuracy".' Lara found that climate change projections were often rejected by sceptics because they were produced by models: 'It was sort of like – "But they're just models".' She considered the following analogy relating models to a common everyday experience was helpful:

> … I said, '[H]ave you ever listened to the weather forecast to find out what you're going to wear today – because you're using a model, you know? … Any time we talk about the future weather, whether it's five minutes away or five years away – you're using a mental model, if not a computer model, to think about the future, because by definition, the future hasn't happened yet. The only way we can talk about the future is using models of some sort, whether they be mental models or computer models.' (Lara)

Padraic also found analogies to be useful for helping non-scientists to understand scientific ideas. He noted that it was important to recognise that analogies are imperfect when trying to explain complicated ideas in simple terms, and to be frank about such limitations when engaging with non-scientists.

Scientists need specific skills when engaging with the media. The high-profile scientists felt that special skills were required when engaging with the media because of a range of issues that are intertwined. To reduce the potential for identification of the high-profile research scientists, who all work in Australia, a relatively small country, in this section we use different pseudonyms that are genderless and not linked to their area of research or earlier quotes in either this or other reporting of different aspects of this research (Smith et al., 2015b).

Our participants reported that sections of the media could be actively hostile to the generally accepted scientific view. Scientist 1, for example, described a specific experience of being interviewed some years before by a hostile, but very popular, radio interviewer. At the time of the radio interview there was considerable public debate around the topic. The scientist knew in advance that the interview, which was concerned with the socio-scientific issue, would be difficult, because the radio interviewer had broadcasted on several occasions his entrenched opposition to the accepted scientific position. Nevertheless the scientist chose to do the interview; he/she is highly committed to doing science that is relevant to the public. As he/she expected, the interview was 'incredibly stressful'. Scientist 1's approach to answering the interview questions was to focus on the relevant science. As he/she said, 'I just *stuck* at it, pushing the same line' (Scientist 1's emphasis). Although involvement in the interview carried some personal cost for Scientist 1, he/she was

rewarded by positive feedback from peers and others, including some regular listeners to the interviewer; it seemed that, under the circumstances, Scientist 1's approach had been successful.

The high-profile scientists reported that they felt that the media often have their own agenda. Scientist 2 noted, for example, that 'they'll always be trying to get you to say something controversial, and sometimes you've got to actually resist the temptation'. He/she reported that that journalists did not always expect him/her to literally answer a question and, in any event, edited his/her reply, so he/she planned his/her responses carefully in advance. Scientist 2 expressed the view that a scientist needed to be quite careful about 'how to get the message out' when speaking to journalists about socio-scientific issues.

Public understanding of science and scientific processes may differ from that of scientists. The high-profile scientists noted that for a productive interaction with scientists, non-scientists ideally need certain understandings about science; however, scientists need to be mindful that non-scientists often lack these understandings. This applies during face to face meetings with the public and during less direct encounters, where the interaction is mediated by journalists, who themselves may lack appropriate understandings.

These understandings about science are intertwined:

(1) The process of development of scientific knowledge involves the weighing up of evidence.

Several of the quotes above attest to the high-profile scientists' view that paying attention to evidence, and to weighing up the value of that of evidence in drawing conclusions, are among the hallmarks of good scientists. Indeed Dean asserted that 'science is primarily an approach for rational decision-making – weighing up evidence'. Being explicit about this process was important, particularly in controversial areas, for, Dean noted, some community groups 'would like to be able to push arguments which are based not on the weight of evidence but on specific perspectives or philosophies'.

Sam described the weighing up of evidence thus:

> So you've got a particular set of observations … [and] you might have ten theories that are consistent with those data, and so you've got to sort of simultaneously analyse those theories in relation to what you've observed, and come to some sort of conclusion regarding which one is better or worse … but simultaneously be thinking – is there a better theory? Can I integrate several of these theories to create a new theory that will match things better? (Sam)

The high-profile scientists felt that the public lacked an understanding of the complexity of this process, and that their interpretation of the meaning of a scientific conclusion could be different from that of a scientist, as we now discuss.

(2) Scientific knowledge is provisional; and always has some inherent uncertainty.

Padraic noted, scientists 'rarely say … "I proved something" [but that] "these results are consistent with [a particular conclusion]"'. The high-profile scientists suggested that this kind of tentativeness was not well understood by non-scientists. As Prue observed:

> [Some non-scientists] still see it as somehow very concrete, very black and white. They don't see that boundary where you're still unsure about many things, you know, … That kind of

> ambiguity at the very boundaries of science, and the process of coming back, checking, modifying a little bit, having another go – I don't think that's understood at all … seldom … I shouldn't say 'at all'. (Prue)

Poor understanding about the provisional nature of scientific conclusions and the process of developing scientific knowledge was seen as an obstacle to productive interactions between scientists and non-scientists:

> I think the classic is the climate change debate. People don't understand risk, they don't understand uncertainty, they don't know how to couch a conclusion in terms of probabilities, and you see this amplified through the media, and I think it's the responsibility of scientists to try to reveal to the public how it is we think, and how it is we go about coming to a conclusion, and the bounds we can put on that. (Sam)

Thus the high-profile scientists took the view expressed by Ivan that 'one of the biggest challenges is to make the public aware that science isn't black and white'. As Prue noted, the public needed to understand that '[science] is an ongoing … activity. Too bad it's a noun … science … should be a verb'. The high-profile scientists indicated that they try to weave these and other ideas about science and the practice of science into the discussion when interacting with non-scientists. Sam noted,

> after the wow factor, I try and bring it into the discussion … [that] what we're talking about is probability and uncertainty and risk, and how you manage that, … And the analogies I use … [are that] every day, every person makes choices based on imperfect knowledge … and how do we make those decisions? And tie that to just the way that we work as scientists, and, in essence, it's really no difference to a common sense approach to everyday life. (Sam)

Overall, the high-profile scientists considered productive engagement with non-scientists required not only elements related to good scientific practice, but also an understanding of the lives, worlds, and thinking of non-scientists, which may be different to that of scientists. This project of productive engagement was challenging; it involved tensions that they could not fully resolve but tried to address. Underpinning their engagement as we noted earlier, was their commitment to making a contribution to society. As Prue said, 'We need more people that understand what science does, what it doesn't do': the high-profile scientists considered it was the role of the scientist to build bridges between science and society that promoted that understanding.

Discussion

In an earlier article (Smith et al., 2015b), we noted that the high-profile scientists saw engagement with non-scientists in terms of a two-way exchange between equals, with knowledge flowing both ways. In their own interactions with non-scientists, the high-profile scientists were committed to an approach that embraced dialogue, and at the same time, understood that productive dialogue required recognition of differences between scientists and non-scientists. The role of the scientist in these interactions included listening to, understanding and responding to the other. The research in this present article underscores some of the complexity of that approach.

It is important to note that while these scientists claim that they approach interactions with non-scientists hoping for a two-way conversation, it is possible that they interpret what it means to have a two-way conversation in a variety of ways – indeed, our interviews

suggest that some of these scientists would be likely to play a more dominant role in an interaction than would others. Nevertheless, because of their high public profile it does appear that these scientists have all successfully interacted with sectors of the public in ways that have encouraged – or at least not discouraged – further interaction.

The high-profile scientists held views about non-scientists' understandings of and about science that in many ways conform to the 'deficiency model' widely discussed in the literature. However, as our earlier article made clear, the high-profile scientists did not see this lack of knowledge as being a deficiency or 'fault' of the non-scientist: indeed, some clearly indicated that scientists had no right to make any demands on the non-scientist's prior knowledge or understanding. For example, as we noted above, Sam observed that 'it's the responsibility of scientists to try to reveal to the public how it is we think'.

The literature suggests that a common response to non-scientists' inadequate understandings from scientists is to 'fill' the knowledge gap by providing clear and correct information. The high-profile scientists in this study have made a different decision about appropriate ways of responding. They understand that engagement with non-scientists is a two-way process rather than a one-way transfer of information from expert to non-expert. For these high-profile research scientists, the 'deficiency model' acts as a guide to what scientists cannot do, or assume, when engaging with non-scientists. To various degrees, then, these scientists articulated their lived experience of relationships of reciprocal respect with the public.

We noted earlier that these high-profile scientists considered they were regarded as representatives of science. As a consequence they felt they, and scientists in general, had a responsibility to think about how they portrayed the institution of science (Horst, 2013) when interacting with non-scientists. Hence, in order to help non-scientists better understand science, the high-profile scientists felt the scientist needs to have clear understandings of the ways the ideas of science are developed and validated and how scientific practices and thinking differ from everyday practices and thinking. However, many scientists may not have given much consideration to these matters if their day-to-day work as a scientist does not require this. Furthermore, as philosophy of science is not included in many university science courses, they may not have been encouraged to explicitly consider ideas about the nature of science when they were students. It was clear from the interviews that this was the case for the high-profile scientists, whose thinking about the nature of science had been developed during the course of their work as a scientist, and from reading, and discussion with non-scientists.

In addition to clear understandings about the ways the ideas of science are developed and validated, the high-profile scientists believe they, and scientists generally, need to be able to explain their science to a lay person – this may involve simplifying complex ideas and requires confidence on the part of the scientist who may feel compromised in scientific terms. Again, for the most part, this ability was not fostered during the high-profile scientists' science studies, either at school or university, but developed from experience through trial and error.

The interviews with these scientists highlight aspects of their lived experience of doing science not generally acknowledged in contemporary science curricula and point to opportunities for including explicit teaching about additional aspects of contemporary science in schools and universities. Students might examine the importance of weighing

up evidence in science and consider the basis on which competing explanations might be judged. Such an examination should include an opportunity to consider the role of probability and quantitative data in coming to a decision. Another priority should be to facilitate explicit discussion of what it means to use models both within and outside science. Students should be explicitly offered an opportunity to consider the strengths and limitations of scientific explanations for everyday phenomena; and to appreciate that, and how, scientific understandings may differ from everyday understandings. These are all aspects of being a good scientist that our participants felt also assisted a productive conversation with the public.

The high-profile scientists spoke of interacting with the media as a means to engaging with the public. They spoke mainly of involvement with the traditional print and broadcast media, and their views of obstacles to engagement with the media were similar to those reported in some of the literature. Interacting with the media seemed to present an ongoing dilemma. As Weingart (2002) notes, 'The most important criteria for journalists in selecting their stories … are different from those the scientific community uses to communicate information' (p. 705). The basis of the high-profile scientists' approach, as noted earlier, is that both sides are fully engaged in a common pursuit and have a positive interest in learning (Tosse, 2013). However, the different agendas for scientists and the media make this kind of interaction difficult and it seemed the high-profile scientists' response was to manage this as best they could, 'pursuing openness in a cautious controlled manner' (Tosse, 2013, p. 50). The high-profile scientists' experiences with the media draw attention to further possibilities for science education including providing students with opportunities to critically analyse portrayals of science in the media, and examine a range of possible genres and framings. A school education that considered the various portrayals of science in the media has potential benefits for both future producers of those media – scientists and journalists – and for future media consumers.

Conclusion

The professional experiences and insights of these high-profile research scientists remind us as science educators that '[o]ur future intending scientists need more than canonical science if they are to operate successfully as scientists: they [also] need the skills to engage with the … citizens they support' (Smith, 2011, p. 1286). Such engagement is no longer the exclusive province of specialist science communicators but has become an expected part of the work of many successful research scientists. Arguably, a preparation for public engagement with science can now be recognised as one aspect of a useful education for both future insiders and outsiders to science (Feinstein, 2011).

Scientists today may be called upon to represent science in social contexts in which their superior knowledge on scientific matters is not valued, or in which the status of scientific knowledge as a salient factor in a real life issue is challenged. In cases where science is acknowledged as important, scientists cannot expect that members of public have a particular level of scientific expertise (Smith, 2011); instead, responsibility falls on the scientist to accept that supporting the public constitutes part of his or her role (Smith & Gunstone, 2009; Yeatman, 2000). The professional experiences and insights of these high-profile scientists foreground the need for science curricula to better acknowledge the changed practices and context of research science. An examination of the ways in which scientists

handle these aspects of their work opens up possibilities for alternative accounts of science in schools and universities. These alternative accounts have the potential to support forms of science literacy that are useful for future research scientists as well as future non-scientist citizens.

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