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Alison Smith

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"Wow, I didn't know that before; thank you": How scientists use Twitter for public engagement.

In recent years there has been a rhetorical shift from 'deficit' to 'dialogue' and 'engagement' in discourse about science communication. The extent to which any rhetorical shift has translated into everyday communications practice is unclear. This exploratory study aims to develop insights into the ways that scientists use microblogging site Twitter for science communication. Users of social media determine to a considerable degree which communicative function their activity can realise, and how accessible it will be to non-scientists; therefore the importance of scientists' assumptions about the process they are involved in and the people they are communicating with cannot be underestimated. Science blogs were heralded for their potential to transform dialogue between science and society, yet studies suggest they have failed to do so. This study investigates reported practices and discourses of U.K and U.S. scientists on Twitter. The analysis employs a theoretical lens informed by Irwin's (2008) taxonomy of 'orders' of engagement and draws on the notion of 'imagined audiences'. I find some evidence of dialogue and engagement talk, however, reported practice does not reflect this talk. Scientists tweet by and large what they find interesting; despite the deficit-like approach of individual scientists, I conclude that given Twitter's unique characteristics, the effect of all this science tweeting does appear to offer the potential to break down barriers between scientists and non-scientists.

Keywords: Science Communication; Twitter; Social Media; Public Engagement

Bournemouth University

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"The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'eureka!', but 'that's funny...'"

Isaac Asimov

INTRODUCTION

In the summer of 2014, geneticist Neil Hall whipped up a 'Twitter storm' by proposing a "Kardashian Index" – a measure of discrepancy between a scientist's social media profile and publication record. Hall's index was more than "just a bit of fun", a pop at scientists with "overblown public profiles"; it was a considered criticism of the role social media platforms such as Twitter have in science communication (2014, p. 2). Hall is quite happy to endorse social media as a useful tool for the sharing of ideas, but he is clearly unsettled by the notion that it is possible for people to build an impressive public profile essentially by shouting louder than others. The 'top tweet', he points out, will not necessarily come from an expert; it will come from the person with the most followers:

> "If Kim Kardashian commented on the value of the ENCODE project, her tweet would get more retweets and favorites than the rest of the scientific community combined" (Hall 2014, p.3).

Communication by scientists to the public is not a new phenomenon. The great scientist-popularisers of the 19th century, such as Charles Darwin, wrote incredibly successful science books to feed a growing public interest (Gregory and Miller 1998). At the great exhibitions and fairs of the 19th century the latest marvels of science and technology were displayed for general audiences (Raichvarg and Jacques 1991). Well before Professor Brian Cox got in on the act, Michael Faraday and Joseph Priestly were busy at it (Broks 2006). However, the attitude of the scientific community toward popularization has varied widely and dramatically over the years leaving something of a "legacy of confusion and ambivalence" (Gregory and Miller 1998, p.82). The rise of the public understanding of science (PUS) movement of the 1980s in the wake of the publication of the Bodmer Report (Royal Society 1985) saw the scientific community embark on a mission to educate the public (Miller 2001). Britain's scientists were told, "It is clearly a part of each scientist's professional responsibility to promote the public understanding of science" (Royal Society 1985, p24). Bodmer went a long way to legitimizing the popularisation of science (Miller 2001). However, one doesn't have to look too hard at Hall's "Kardashian Index" to detect an undercurrent of the 'Sagan Effect' - whereby a scientist's popularity with the general public is inversely proportional to actual science being done (Shermer 2002).

Today, engaging the public through science communication has become a mainstream activity (Bowater and Yeoman 2013), and the call for scientists to be more engaged with the public has never been clearer (RCUK 2015[1]). Social media have been presented as a promising opportunity to do just that (Bubela et al. 2010; Van Eperen and Marincola 2011; Wilcox 2012; McClain and Neeley 2014). The *I fucking love science* Facebook page[2] has nearly 20 million Likes, and in 2012 the landing of NASA's Curiosity rover on Mars generated 1.2 billion Twitter messages, 17.4 million Facebook hits, and the Twitter message announcing the landing was retweeted 72,000 times (Pinholster and Ham 2013), revealing an enthusiasm for uncontrolled engagement among those interested in science (Stilgoe et al. 2014, p.9). The reality for science communication in the 21st century is that "scientists, their institutions, and the scientific knowledge they produce are now entangled in new media environments" (Brossard 2013, p.14096). Platforms such as Twitter appear to offer the tools with which to apply the theory of public engagement; allowing users to have conversations, form communities, share content, and build relationships (Kietzmann et al. 2011). Indeed, as Hinton and Hjorth (2013) argue, "[i]f there is one word that summarises the particular quality of social media it would be 'participation' (p.55).

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[1] http://www.rcuk.ac.uk/pe/

[2] www.facebook.com/IFeakingLoveScience

The majority of public engagement activities are *ad hoc*, informal, intuition-driven approaches (Turney 2006; Miller 2008). In practice, it is individuals or small groups of scientists who come into contact with members of the public rather than 'science' as an institution or establishment (Davies 2008); arguably social media is perhaps the ultimate *ad hoc* and informal public engagement activity. Users of social media are able to determine to a considerable degree which communicative function their activities can realise, and how accessible their communications will be to non-experts (Kouper 2010; Trench 2012; Mahrt and Puschmann 2014). Therefore, individual scientists'

> "assumptions about the process they are involved in and the individuals they are interacting with will have an important impact on those processes" (Davies 2008, p.414).

This study reflects an interest in social media as an emerging channel for interaction between scientists and society (Riesch and Mendel 2014; Mahrt and Puschmann 2014; Bell 2012). It builds on work which examines scientists' ideas and assumptions about public engagement (Davies 2008; Besley 2014; Jensen and Holliman 2015), and expert thinking on the public (see for example Cook et al. 2004; Burchell 2007).

This study is concerned with *Twitter*, the most popular member of a group of social media applications called micro-blogs (Kaplan and Haenlein 2011) Twitter's central feature is the exchange of short messages of 140 characters – 'tweets' – that are mostly real-time status updates (Kietzmann et al. 2011) posted by users in response to the question "What's happening?" Twitter's 302 million monthly active users produce between them 500 million tweets per day[3]; a stream of "short messages that range from humor and musings on life to links and breaking news" (Marwick and boyd 2010), which for the most part are of an ephemeral nature, without any attendant obligation to respond (Kietzmann et al. 2011).

On the continuum of social media classification, micro-blogs are halfway between traditional blogs and social networking sites (ibid). Although senior executives at Twitter have been at pains to stress Twitter is *not* a social network (Perez 2010), it convincingly passes for one according to boyd and Ellison's (2008) functional definition of a social network site as: one in which users are able to articulate and make visible their connections, and navigate the connections made by others within the system (p.211). Or as Fitton et al (2010) more elegantly put it, Twitter is "a digital abstraction that represents who you know and who you're interested in" (p.10).

Using in depth interviews, I examine the way in which scientists talk about their use of Twitter for public communication. I want to learn what role Twitter plays for scientist-communicators: who are they talking to, what are they saying and why, and what impact do they think their use of Twitter has?

LITERATURE REVIEW

I have drawn on literature from the field of science communication research, and as others have done (see Jensen and Holliman 2015), I use Irwin's (2008) orders of public engagement taxonomy as a conceptual framework for assessing scientist-communicators attitudes about, and practices of, science engagement. In exploring expert thinking on the public, I draw on the notion of 'imagined audiences' (Marwick

[3] Twitter usage statistics www.twitter.com

and boyd 2010). I also review the literature on science blogs and science blogging, which offer insight into to any study of micro-blogging. I follow Brossard's (2013) recommendation "not to reinvent the wheel", and draw on empirical and theoretical work from the fields of digital media practice (p.14100). I begin by fixing a definition of *public communication* and *public engagement* in the context of this study.

Are we communicating or engaging?

'Public communication' or 'science communication' is broadly defined here to include any type of planned interaction where scientists communicate with non-scientists about science and technology outside of a classroom setting (Besley 2014). The well-established practices of 'science outreach' have involved scientists and science communicators 'educating' members of the public (Wright and Nerlich 2006). Scientists have been heavily criticized for imagining their relationship with the public solely on the basis of a deficit in scientific knowledge

> "and for reducing the complexities of science in society to a problem of communication where the responsibility of science is to pass on simplified scientific messages to the 'people'" (ibid. p331).

The axiom of this approach, 'to know science is to love science', holds that a "lack of knowledge is the driver of negative attitudes and biased risk perceptions" (Bauer et al 2007, p.83). It relies on an approach to communication that became known as the 'deficit model' (Gross 1994), a one-way, top-down communication process, where science 'facts' flow from scientists to inform an ignorant public (Miller 2001). *'Dialogue' and 'engagement'* models came to be presented as the acceptable alternative to the deficit model from the late 1990s, against a backdrop of public controversies over BSE and GM foods (Bucchi and Trench 2014). An influential report, *Science and Society*, published by the House of Lords (2000), acknowledged the limits of science communication based on a paternalistic, top-down science public relationship and detected a "new mood for dialogue" (House of Lords 2000, p.37). 'Engagement talk' has taken hold in the UK and elsewhere, and the shift from 'deficit to dialogue' is recognised and repeated by scientists, policy-makers, social scientists and science engagement practitioners alike (Stilgoe et al. 2014).

From deficit to dialogue?

Models of communication are one of the key theoretical concepts in science communication, yet very few explicit models have been designed and proposed. Over the past two decades, science communication researchers and practitioners have sustained a discussion about the "limits of inherited models and the characteristics of models that are more appropriate for the present day" (Bucchi and Trench 2014, p.3). The claimed shift from a deficit model of public communication of science to one based on dialogue remains a powerful narrative in the field, and in many accounts dialogue is seen to be inherently superior to deficit, and the shift is often presented as both evolutionary and irrefutable fact (ibid.). Despite a proliferation of dialogue processes (for a typology see Rowe and Frewer 2005), ten years of research evidence has questioned the scale and reality of the shift from deficit to dialogue (see for example Irwin 2006; Wynne 2006, 2011; Lezaun and Soneryd 2007; Chilvers 2008; Sturgis 2014; Jensen and Holliman 2015), and the degree to which science communicators have adopted the goals of the 'engagement agenda' (Burchell 2007; Davies 2008; Jensen and Holliman 2015). Like others (Irwin 2008; Jensen and Holliman 2015) I do

not intend to take a view on whether deficit or dialogue is fundamentally superior, nor whether there is an inevitable progression from one to the other, rather both models are assumed to have a role in public engagement.

Scientists' understanding of public engagement

Irwin's (2008) 'orders of public engagement' taxonomy provides a useful conceptual framework for assessing scientist-communicators attitudes about, and practices of, public engagement. Irwin defines the deficit-informed, 'science outreach' approach as 'first order', and dialogic approaches that aim for a two-way conversation, allowing an exchange of perspectives between the sciences and the public, as 'second order'. The taxonomy also provides for a 'third order' of approaches that seek to set the sciences in a wider social context, addressing societal concerns and priorities, involving multiple stakeholder perspectives (ibid). Previous research exploring scientists' understandings of public engagement finds that first-order, deficit-informed discourses of one-way communication and unreceptive publics dominate (see for example Davies 2008). However, a more recent study by Jensen and Holliman (2015) found that a significant minority of scientists and science communicators defined public engagement in second-order terms, suggesting that dialogic approaches have been at least partially adopted.

Social media and science communication

Scientist's use of social media for public engagement has not been subject to a great deal of examination, but within the scholarship science blogs and the practice of science blogging have received the most attention (for a review see Trench 2012; Mahrt and Puschmann 2014). Traditional blogs and micro-blogging both provide a modern means of conducting science communication with a broader public, and have functional similarities suggesting that insights from scholarship concerning the former may illuminate a study on the latter. Both allow users to publish a mix of opinion, news and other types of content. Both also support interactive features, including conversation. However, while Twitter facilitates real-time conversations among individuals and groups, traditional blogs are less about staying connected synchronously and more about facilitating rich, often lengthy conversations that can be traced back through the comment fields on the blog itself (Kietzmann et al. 2011).

Bubela et al. (2010) argue that new media are “fundamentally changing the nature of science communication” and they single out science blogs for their ability to create dialogue between scientists and lay publics (p.516). Yet studies show popular science bloggers have "little compulsion to extend their audience reach beyond those already interested in the topic" (Ranger and Bultitude 2014, p.14), and science blogs act as a 'virtual water coolers' for professional scientists or future professional scientists. The sense of community with shared context and cultures acts as a barrier to participation by 'outsiders' (ibid). Science blogs with their personal, often intimate, character appear to have the potential to open up aspects of scientific research previously hidden from the general public, and in so doing serve an important function, because “unlike laws and sausages, the public should see science during its manufacture” (Wilkins 2008, p.411). Yet, Trench (2012) found less than a quarter examined provided "even occasional looks behind the scenes of science".

Setting to one side the expectations attached to science blogging more broadly, the findings are more positive. On a smaller scale bloggers are able to form functioning and diverse online communities (Riesch and Mendel 2013), see their audience as a

potential resource, and blogging as part of an on-going diverse conversation (Bell 2012). The potential of scientists' blogging to contribute to reshaping relations between sciences and publics is evident, argues Trench (2012) but it appears largely to be unrealised. Blogging as a web tool, concludes Kouper (2010), "has no magic properties on its own" and requires the concerted effort of the actors involved to rethink the role of blogging in the promotion of participatory science (p.8).

While Twitter shares certain functional characteristics with blogs, Kaplan and Haenlein (2011) identify three distinct characteristics they argue make micro-blogging popular, and which appear to offer insight to the current study. Firstly, the ability to tell the world what you are doing at a particular moment creates "ambient awareness", where a series of tweets can generate strong feelings of closeness and intimacy (ibid, p.107). Secondly, micro-blogs enable a unique form of communication: where 'following' relevant or interesting accounts conveniently reduces the effort associated with accessing information; single tweets can cascade through networks of followers, creating 'buzz', substantially increasing impact and credibility; and finally, many tweets contain links to web pages, or traditional blogs, acting like banner advertisements which try to motivate users to 'click-through'. Thirdly, micro-blogs are the perfect tool for "anonymous voyeurism": keeping updated without an obligation to react and respond (ibid. p.108). Indeed, the attraction of this is illustrated by the fact that most Twitter users observe, rather than contribute (ibid.).

Expert thinking on the public?

A shift to dialogue in science communication also requires that those who communicate conceptualise publics in a more "sophisticated" way, acknowledging the knowledge, values, attitudes and beliefs that they bring to more "symmetrical and interactive exchanges" (Holliman and Jensen 2009, p.35). However, there exists a large qualitative literature that suggests scientists have a range of negative views about the public; almost universally scientists agree the public are inadequately informed, uninterested in becoming more so, and furthermore that they are irrational, emotional, and stubborn in the face of new evidence (for an excellent review see Besley and Nisbet 2011). Scientists who actively engage and interact with the public, though, tend to be more charitable (Blok et al 2008; Davies 2008), viewing them as moderately informed, keen to learn about science, and not confrontational (Pearson et al. 1997).

Imagining the audience online?

> "...there is deafening ambivalence from Twitter. And the gulf between the aspiration to communicate and the reality of so few people caring looms large and dark."
>
> Maynard 2015

When engagement shifts online, conceptualising publics runs into further problems. 'Publics' in mediated conversations, such as those on social media, can be thought of as 'audiences'. In Twitter's directed-friendship model, connections are made unilaterally; users choose whom to follow, and each has their own group of followers (Hinton and Hjorth 2013). Last year astrophysicist Neil deGrasse Tyson[4] topped *Science's* list of the 100 most followed scientists on Twitter (Travis 2014), and at the time of writing has some 3.6 million followers. Followers, however, provide a fairly imprecise indication

[4] @neiltyson

of 'audience'. The majority of Twitter accounts are public and can be read by anyone; given the way tweets are consumed and spread it is virtually impossible for Twitter users to account for their potential audience (Marwick and boyd 2010). Every participant in a communicative act has an *imagined audience*, and we present ourselves differently depending on who we are talking to, and where the conversation takes place (Marwick and boyd 2010). 'Context collapse' in online environments means users must address a diverse audience (employers, other scientists, general public, family and friends) with the same message (ibid). Self-presentation on Twitter is through a constantly updated 'feed' of tweets (Marwick and boyd 2010); as tweets are public by default, users can only present a single identity to groups of people who would ordinarily merit different sorts of identity performances (Goffman 1959).

In the context of calls for scientists to engage with the public, science blogs have been recognised for their ability to create dialogue, but to date expectations have not been met. Micro-blogging is similar but not the same as blogging, and has a discrete set of functional characteristics. How then do scientists understand their use of Twitter for science communication? When it comes to expert thinking on the public, we start with the idea that scientists are likely to take a rather dim view of the public. As Blok et al. (2008) argue, "constructing lay-people along the lines of the 'deficit model' represents a powerful social tool" (p.191). Online, the audience seems both limitless and unknowable, and it is difficult if not impossible for users to vary self-presentation strategies for different groups (Marwick and boyd 2010). As I set out in the rationale for this research, users of social media are able to determine to a considerable degree which communicative function their activity can realise, and how accessible it will be to non-scientists; therefore the importance of scientists' assumptions about the process they are involved in and the people they are communicating with cannot be underestimated (Davies 2008).

METHODOLOGY

My purpose here is to gain insight and understanding into the ways that scientists think about their use of Twitter. How do they understand: the role it plays in their communications with the public; who is it they are talking to; and to what effect? I adopt a qualitative methodological approach, using elite interviews in order to generate "in-depth understanding and highly valid accounts of participants' lived experiences" (Jensen and Holliman 2009, p.65).

The community of practice around science outreach and public engagement is ill defined and the boundaries of the population and its precise demographics and characteristics are unknown (Miller 2008). In addition, the use of social media for science communication is an emerging population, so obtaining a representative sample of this population in quantitative terms would be challenging. In order to maximize validity within the bounds of practical constraints this study uses purposive sampling. I describe my process below.

I recruited participants through Twitter, using the results of a Twitter search for #scicomm, a hashtag commonly used by science communicators. Information in Twitter biographies was used to single out accounts that met my criteria for participation: namely, that they were a scientist, based in the UK or the U.S., who appeared to be actively using social media for science communication, which I judged by number of tweets and followers.

Jensen and Holliman (2009, p.68) caution that an "often unspoken and uncomfortable lack of engagement between scientists and social researchers" is a

potential challenge in conducting studies of science-society relations. The lack of trust between the two communities, illustrated by the 'science wars' (Mellor 1999) can make the recruitment of scientists difficult. However, an invitation to participate in this study was met with enthusiasm by potential research participants. Of those contacted, 56 agreed to be interviewed, and 14 were purposively selected to ensure a mix of early career scientists and senior scientists, across a range of disciplines. Nearly three quarters of respondents to my interview requests were female, however, in my final selection the gender balance was eight female and six male.

Participants included particle physicists, astronomers, engineers, oceanographers, geochemists, and planetary scientists, in locations across the UK and the U.S.

The data collection involved 14 semi-structured interviews conducted by Skype and telephone between January and March 2015. Interviews typically lasted 45-60 minutes and were recorded and transcribed, maintaining the anonymity of participants. Discussion was focused through the use of a semi-structured interview schedule; topics included participants' perceptions of public engagement in general, their views on the role and potential of social media in science communication, their motivations for, and experiences of engaging with the public on social media.

As Lilleker (2003) points out, interpreting elite interviews can present problems in the case of individuals who may be tempted to "rewrite history in their own favour" (p.211). In the case of this study, for example, I asked scientists to talk about the 'public' and 'public engagement'. They do not do so in a vacuum. As I have already mentioned, some scientists hold less than charitable views about both the lay public and social scientists. In my dual role as a member of the lay public and as a science communications researcher, it would not be unreasonable to consider that my interviewees may take this into account and alter their talk about their practice and perceptions to reflect what they think they ought to say. For example, participants familiar with research in the field (as a number were) may describe their social media communications practice in keeping with the rhetoric of 'dialogue as progress'. My interviewees may also be more generous towards lay-knowledge than they would in conversation with a fellow scientist, for fear of either offending the layperson interviewing them, or because they wish to reject certain professional stereotypes.

Data were qualitatively analysed using principles from discourse analysis (Silverman 2013) to: examine how particular meanings were constructed; to inform interpretive coding of the data; and to identify key themes and concepts. In the discussion that follows, I show verbatim extracts as examples representative of a broader selection, rather than comprehensive of the themes I found. The sample is not representative of the larger population under study; however, the insights are valuable for the purposes of the research in examining understandings of communications processes and audiences.

FINDINGS AND ANALYSIS

Engaging with the public

I asked my participants to talk about their understanding of the differences between science outreach and public engagement. Talk is wide-ranging, but in the data the most frequent construction is the notion of public engagement as "education", with a set of closely related ideas, ranging from "raising awareness" and "understanding", to "translation of scientific research" and "providing information", and also "to inspire".

The first-order aims of increasing scientific knowledge dominate, and only a minority mention "conversation" and "interactivity", however, their definitions are still first order, conflated under the brand of 'engagement', as exemplified in the following extract:

> "I guess it would be either scientists or institutions...groups...trying to raise understanding or an awareness about science generally or a specific scientific concept or topic with some area of the public [...] it is more of a two-way conversation" (S02).

This extract emphasises the aims of 'engagement' as raising understanding and awareness. A few participants are hesitant and one struggles to provide any definition of engagement at all: "I don't have an instant definition...any communication activity that is outside your immediate professional circle" (S14). While three participants tell me they are familiar with the idea of a shift to engagement, and cite science communication research, interestingly their own definitions are still first-order. Also evident is a level of rejection of institutional efforts to encourage 'engagement':

> "I have been to all these science communications conferences...what the hell does that mean?...you think 'for fuck's sake, I'm just trying to communicate and all you're doing is telling me I'm an elitist'" (S12).

Our conversations turned to motivations for public engagement. Although a range of motivations are expressed, enthusiasm for and love of science is a major theme: "I think science is cool and the natural world and the things in it are just amazing!" (S10). Intrinsic motivations include finding talking about science "enjoyable", and "rewarding", for example: "when someone writes and says, 'this is really fascinating – I never even knew this existed'" (S09). When talking about intrinsic motivations, scientists' representations of public engagement are first-order; in the examples above, motivations all assume 'communicating science'. Within the extrinsic motivations, first-order definitions dominate:

> "it allows you as a person who knows this stuff to help other people benefit [from your knowledge], and not just hoard it for yourself" (S01); "I believe that people should have an appreciation of science" (S07).

In this example again, 'communicating science' is seen to be the key issue, and facts flow in one direction from scientist to non-scientist. Also within the data, first-order characterizations of science communication as "duty", "professional responsibility" and: "wanting to make the research connect back into the people who are paying for it" (S01).

What is the role of Twitter?

It was clear participants felt Twitter played a "big role" in science communication. It was "normal", ubiquitous, and necessary:

> "...it is how people are communicating...if you are looking to reach out and talk to someone and get to know people who are interested in what you are doing, then you have to be on social media – it is as required as having a telephone line" (S10);
>
> "I think most people, a lot of people, get their primary source of information from social media" (S11).

Most of my participants find Twitter "easy to use" and "enjoyable", though there is clearly a continuum of enthusiasm. Twitter also straddles personal and professional

boundaries: "I tend to Tweet when I don't have something else to do...I'm on my phone and I'm checking Twitter" (S10). One participant tweets about his fellowship when his daughter goes swimming:

> "it is 12 or 13 hours a week...I can't face work so I'll tweet...it is slightly erratic but that is how I work and live in a way" (S05).

Although in our interviews the focus of the talk was communicating science to the general public, they all used Twitter to communicate with their peers, students, and scientists in other disciplines. Many use it to follow developments in fields that interest them, to ask questions of other experts, or to seek out work opportunities or academic collaborations. For these scientists Twitter use crosses professional and personal boundaries. It also serves to break down boundaries between scientific hierarchies, welcomed by some of the younger scientists; described below by this doctoral researcher:

> "without knowing it I communicate quite regularly with research fellows, and professors...I'd probably be quite intimidated talking to them on a face-to-face basis" (S09).

#scicomm via #socmed

When we talked about how they use Twitter, constructions of public engagement are much more complex than when they talk generally. Talk now more often reflects second-order representations of communication:

> "you can have a conversation on Twitter...with people who are communicating with you – you can ask and answer questions, you can hear each other's viewpoints, you can be challenged of challenge..." (S02)

Within this talk are lay knowledge, other points of view and a suggestion that publics could be a resource:

> "there are a lot of people that don't have degrees...but they still know a lot – a lot more than people who do have those degrees...and you really have a chance to tap into that a lot more, because everyone is kinda levelled by the social media environment" (S01);
>
> "I always say, astronomy is the one branch of science that the amateur can make a truly valuable contribution to" (S08);
>
> "a diversity of voices...one of the big goals of science communication is to show that anyone can be a scientists, or can think scientifically" (S02).

Here it is interesting to note that some participants make specific reference to the technological affordances of Twitter as helping to achieve more 'participatory' outcomes. Some expressed this more strongly than others:

> "there is a logic in the tools...I suppose I can fantasise that the tools could be used...there is something democratic about them" (S13).

In this extract above, there is evidence of hesitant third-order thinking.

Broadly though, all seem to be of the opinion that the more science communication that goes on the better; "saturating the market, so to speak, and trying to get the information out there" (S04). Being able to communicate directly with the public is thought to be useful and important, as is being able to tap into dispersed or otherwise hard to reach audiences. The examples below suggest a first-order

construction of one-way, top-down, science-led communication, emphasizing 'public ignorance' and 'education':

> "I definitely know that I am able to reach people around the world [...] you are encountering people that otherwise would have been left out" (S01);
>
> "the person who's been sort of ignoring something" (S04).

Despite the feeling that Twitter could help them speak to anyone anywhere, engagement is rarely solicited, rather:

> "I don't tend to directly welcome engagement...if they have a question or a comment, I try to engage – if someone tweets at me, I try to tweet back" (S10).

Acknowledging enthusiastic tweets from the public (such as the one in the title of this paper) in response to a tweet is seen as "important", however, interaction appears to be contingent on certain behavioural criteria: "if I perceive [the user] as reasonable and intelligent and sympathetic to the science cause I will interact" (S04). However, there was evidence that some reflected on their practise: "I should try and start a dialogue, but it is very time consuming" (S01) and

> "I'd like a bit more discussion but then I guess that's down to the things I post – that's I suppose what I'd like to improve in the future" (S09).

There is a sense then, in these extracts that there is a knowledge that 'dialogue' is both the 'right' thing to do and it is to be desired, which can be understood as a small shift towards second-order thinking.

How scientists talk about the public?

My participants comprehensively describe the public in positive terms. They have "a very high level of interest in science" (S01), are "willing to engage" and are "enthusiastic". The implicit assumption in this generous description, however, is that public are a benign and fairly uniform group of non-experts; suggesting a first-order communication style.

When I ask them to talk specifically about levels of scientific literacy, first-order definitions of publics as deficient and problematic arise. Some suggested the public could be "easily mislead" by "anti-science" information. Likewise, the extract below downplays the role for anything other than science facts:

> "people don't just form their opinions on facts, whether we like it or not, they take a lot of different things into account" (S10).

However, some talk of "field specific jargon" in science hints at more complex second-order constructions of publics, and allows for differing levels of expertise:

> "it has nothing to do with [a person's] education...it is literally jargon, I mean...I can't read a physics article" (S10).

This respondent reflects on the specialisation of science, conceiving of herself as a 'public' of another discipline.

Within the talk, one definition alone reflected third-order representations of engagement; the participant in the extract below considers a more central and normative role for the public in matters of controversial science: "these citizens...they've got to have some power...they've got to be able to say no" (S13).

Who is listening?

That the potential audience is both unknown and unknowable emerges in the data as a strong theme. Participants do not conceptualise their audience on Twitter in particularly diverse or varied ways; most participants distinguish between a science, or science interested and a non-science, "general public" audience, for example: "scientists, science communicators, and that includes a big group of science writers" (S02); "someone who is already interested in science...science dudes" (S12). Interestingly, despite Twitter's potentially unlimited audience, and their driving motivations to share their love of science, for the majority of participants there was no attendant sense of desire, or need, or indeed expectation to reach a mass audience. In fact the opposite was often true:

> "even if it is just one or two more people, per activity or even per account, that is still making a difference" (S01).

Some of my participants tell me that they try to envisage who will read their tweets. The extract below suggests this scientist visualises their audience as sub-groups of the people who follow them on Twitter:

> "I have little crowds of avatars I my head who I imagine my tweets going out to" (S02).

However, aware that tweets are public she adds:

> "sometimes you get a response totally out of the blue, not from the group you expect, and that will be interesting [...] there's this whole group of people who if you just showed me their [Twitter] bio, I would not have followed them, but we had some kind of interesting interaction so now we're following each other and we're 'best mates' on Twitter" (S02).

Who is contained within the imagined audience clearly has an impact on what is communicated:

> "the vision in my head...this person, like a manager of a company or something, who is perfectly intelligent...but not involved in science...I tweet things I think that person might find interesting" (S10).

A few suggested their imagined audiences always include their mothers, PhD supervisors or employers, a litmus test of acceptable communication, which effectively served to censor their tweeting.

The majority of my participants also invoke an unwelcome audience, the "science trolls". 'Trolling' is framed as an activity undertaken by those holding particular religious (i.e creationist) or political views; described by one participant as "right-wing, rambling, Tea Party lunacy" (S08). Or simply: "those who get sucked into various kinds of pseudo-science like astrology" (S02). Trolling elicits a relatively uniform response; "if people get abusive then I block them" (S08). Many had experience of trolling, although it did not appear to have an effect on the content of their communication. Rather there was talk of a sense of community around online incivility (see also Anderson 2014; Mendel and Riesch *forthcoming*) emerged in their talk:

> "when someone says something obnoxious or unscientific I have a pretty good group of followers that will jump down their throat" (S10).

Some scientists do not direct their tweets to others at all; their audience is "me": "there are some things [I tweet that] are so truly obscure I'm just doing it for myself" (S01); "I think half of what I am doing is a diary" (S05); "I tweet about things that are interesting to me...and I tweet about things that I am doing relating to that" (S04). However, as

Marwick and boyd (2011) point out while users are not directing their tweets to others, they are not tweeting into a void, they all have followers and their tweets are public. Rather, the implication is that other people's reactions do not matter (ibid), typified in the following extract:

> "let me just tweet what I like, instead of worrying so much about them, and then it will attract the people who like that stuff and then I don't have to worry about the rest" (S04).

Marwick and boyd (2011) argue, "tweeting for oneself suggests a true-to-self authenticity" (p.119), whereas strategically appealing to followers could be perceived as 'inauthentic' behaviour.

So I asked them about their strategic use of Twitter; how did they know what worked and did they then go out of their way to do more of it? Was gaining followers and reach important? Despite a wealth of online resources and guides, many relied on intuition or a feel for 'what works' based on personal experience of 'what works'. A few of the more prolific users have become 'experts' in social media for science communications and write and present on the subject. Some were able to talk about ideas for improving their tweeting, one early career scientist told me she copies the approach of Twitter accounts she feels have merit:

> "I've seen some really great social media accounts that seem to have personality...ones I had a positive feeling towards" (S11).

A few talk about the make-up of an ideal Twitter feed, balancing retweets and original content, or what time of day it is best to tweet. Some described adapting their approach in response to retweets and favourites, or increases in their numbers of followers, as well as anecdotal feedback from other users. It seems many see Twitter as 'fickle', where efforts invariably do not translate to increases in followers, favourites or retweets. For some this appears to justify a *laissez faire* attitude to taking too much of a strategic approach to communication, typified by this response:

> "I seem to have caught on...[I] share what I think is fun and what I enjoy and it worked...so when people say 'how did you do that?', I'm like, 'I don't really know'" (S04).

Leading her to conclude:

> "I think as a science communicator the best thing we can do is be engaging...be accurate and do our best to reach the audience that happens to reach us" (S04).

Twitter represents a significant investment of time for my participants, so I am surprised by the modesty of the ambition:

> "I just do it for the fun of doing it – if it reaches people, great – if it helps people, great" (S01).

Some said their twitter feed is, "a little bit like entertainment" (S04), a stream of facts where; "someone can take that and drop it into a conversation" (S01). Where grander ambitions and motivations are expressed, such as increasing the number of women in science, the sense of a lack of efficacy is expressed: "I'm not narcissistic enough to think I am going to make a huge difference..." (S11) Others think that their tweets may help in a different way, wondering if their efforts:

> "kinda humanize [scientists]... hopefully by extension that will make people think 'that person is not different to me...'" (S12).

While a number agree the public is keen to know more about scientists as people, what they do, and how they do it, they remain equivocal about the actual impact of this type of communication: "does that translate to literacy? I just really doubt it..." (S12).

Drawbacks and challenges?

I concluded by asking if there were any drawbacks and challenges, and two main themes were evident in the data. Firstly, there is the matter of time and resources. Twitter is a '24/7' platform, and there is a concern that:

> "it can be hard to make sure that you are putting an appropriate but not inappropriate amount of time into social media" (S10).
> "the prolific nature of it all [...] it can be overwhelming" (S01);
> "it sort of turns into a burden a bit, we all have this stuff we are under pressure to do with communication...it is turning into a job" (S12)

More worryingly, there is the sense that abuse is frequent and to be expected, and most participants offered an anecdote or two about their recent experiences: Twitter can be an uncomfortable place; "you can be harassed on twitter...women are more harassed than men" (S02); "I saw [...] the backlash that women of intelligence and power get on social media for having opinions" (S11). One participant pointed out:

> "not everyone [...] has the privilege of accepting the same amount of risk [...] although it seems like it is totally accessible to anyone...I am not entirely sure that it is, it might seem scarier to some people than others" (S02).

DISCUSSION

> "Really, I don't know, we're all just doing a big experiment on ourselves, we're doing social media, we're scientists, science communicators...we're hoping for the best, we have no idea if it is working or not, we don't know if it is a good use of our time, or a waste of our time...in twenty years I might have a better idea...what we are really doing is taking a risk by spending a whole bunch of our time on something that may or may not be good for us, and may or may not be good for science communication and outreach" (S02).

This study seeks to add to previous work examining scientists' understanding of public engagement (Davies 2008; Jensen and Holliman 2015) and scientific understandings of publics (Burchell 2007; Cook et al 2004; Davies 2008) by attempting to provide insights into the ways that scientists use Twitter for science communication.

Participants in this study defined engagement and talked about their motivations for talking to the public in an almost entirely deficit-informed way. Even participants who seemed familiar with the rhetorical shift towards 'engagement' and 'dialogue' failed to provide a second-order definition, and others expressed uncertainty or confusion.

Other recent work on scientists' understanding of public engagement does find minority discourses that reflect more complex two-way constructions of public communication (Davies 2008), suggesting that second-order thinking on engagement has been at least partially adopted (Jensen and Holliman 2015). So I was surprised at the extent to which communication about science is entirely driven by scientists, with such "a silence around public voices" (Davies 2008, p.420).

My key finding was that when engagement-talk focused on the use of Twitter for science communication, constructions of public engagement became more complex and nuanced. Second-order ideas such as lay-knowledge and two-way communication

appear. Some scientists made explicit references to the technological capabilities of Twitter as a mechanism to achieve more participatory outcomes; and one went as far as introducing third-order representations. Both Trench (2012) and Kouper (2010) argue that blogging as a web tool has no magic properties on its own. I would like to advance, as a tentative hypothesis, that Twitter has a set of commonly understood features and characteristics that influence the assumptions of the people using it.

Being able to communicate directly with the public was clearly valued, and while tweets were generally written for a science-interested lay audience, engagement was not solicited. Talk about engagement on Twitter, therefore, does not reflect reported practice, although some participants reflected on the necessity or desirability of engagement "in the future" (S09).

A shift to dialogue requires that scientists conceptualise publics in a more sophisticated way. Unlike previous research, which has shown scientists tend to have negative views of the public (Besley and Nisbet 2011), participants in this study described the public in enthusiastic terms. They expressed both intrinsic (e.g. for pleasure) and extrinsic motivations to blog (e.g. spreading the message about science; duty). Engagement is not actively sought, however, participants nevertheless found it rewarding when they knew others shared their enthusiasm for science, indicated by replies or retweets.

My participants showed little awareness of audience beyond a fairly straightforward division into science and non-science audiences. By and large they tweeted what they found interesting and inspiring. After Marwick and boyd (2011), one reading of this phenomenon is that the audience, however it is comprised, simply does not matter to them; rather, being true to oneself, or 'authentic', is more valuable than strategically appealing to followers. Writing in 1977, communications scholar Rae Goodell, argued that the scientific community was able to exercise a powerful system of social control over its members who popularise. Hall's (2014) Kardashian-Index with which I set up this paper seems to represent such a form of social control, and could be one way to understand the modesty of ambition.

CONCLUSION

> "Communicators might also consider that factual communications—while they may be inspirational—probably have little lasting effect on knowledge levels. People will pick up the knowledge they need for the task at hand, use it as required, and then put it down again. It will not be ready to hand when the survey interviewer next asks them if, for example, an electron is bigger than an atom"
>
> (Miller 2001, p.118).

Despite evidence of dialogue-informed engagement talk my participants didn't practice it, and clearly did not view their tweeting in this way. Their sense of efficacy was low and there was no desire to attract large audiences.

Science blogs, according to Trench (2012), have failed to provide a behind-the-scenes perspective on science. Twitter is part of a broader life, straddling professional and personal boundaries, and "increasingly infiltrating everyday media practices" (Hinton and Hjorth 2013, p.30). Its conversational immediacy, support for 'anonymous vouyerism', and the ease with which tweets can be read and spread, makes it very

different from science blogging. As a result, regardless of the engagement agenda of individual scientists using it, Twitter may significantly change the nature of science communication. Twitter creates 'ambient awareness' which can generate strong feelings of closeness and intimacy (Kaplan and Haenlein 2011). If *en masse* these scientists tweet about their lives, organise social events and collaborations, challenge their superiors, post pictures of their pets or their particle colliders, all in plain sight of a potentially limitless audience, then there seems to be an opportunity for Twitter to fulfill this role. As Jackson and Lilleker (2011) point out in the case of UK Members of Parliament's use of Twitter, this can arguably break down barriers between scientist and non-scientists, and encourage greater trust and interest and build an impression of scientists that surpasses pejorative media narratives.

Ranger and Bultitude (2014) argue that while their popular science bloggers resembled "transmitters" rather than "engagers", the phenomenon did not resemble a classic deficit-model approach, as the bloggers did not see themselves filling the "knowledge vacuum in the scientifically illiterate general public" (Miller 2001, p.116). I feel able to say the same about the participants in this study.

These interviews, while insightful, were limited in scope and the applicability of its findings and conclusions needs to be tested further. Specifically, I acknowledge that the opinions and Twitter approaches presented here do not necessarily represent those of all scientists. The findings can serve as an initial step in the investigations of the relationship between Twitter and public engagement with science. Further research would usefully include a content analysis of their tweets or who follows them. Finally, the study would benefit from extending the analysis to lurkers, i.e., those readers who follow scientists on Twitter but do not engage.

As a final concluding point, I did not address in depth the drawbacks and challenges of Twitter that scientists talked about. Prominent in the data is the idea that abuse, and harassment is frequent and expected. It would be wrong to assume that Twitter is open and accessible to anyone:

> "not everyone [...] has the privilege of accepting the same amount of risk [...] it might seem scarier to some people than others" (S02).

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