François, K., Löwe, B., Müller, T., Van Kerkhove, B., editors,
*Foundations of the Formal Sciences VII*
Bringing together Philosophy and Sociology of Science

# On the philosophical talk of scientists

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## 1 Introduction

This paper analyses how scientists talk and write about philosophical topics, as part of a larger project on scientists' views of philosophy of science. It aims to describe how scientists themselves think and learn about the nature of science, and what they would like other people to learn about it. A total of 30 popular science books were analysed for how they treat philosophical topics on the nature of science. Additionally, 40 academic scientists were asked in a series of semi-structured interviews questions based on the philosophical topics that were found discussed most often in the books. In the interviews, five philosophical topics were dealt with in detail: The demarcation question of "what is science", the philosophies of Popper and Kuhn, Occam's razor and reductionism, which reflect the most common philosophical themes in the popular science books. This paper will focus on two of these topics as characteristic of scientists' talk of philosophy, the general question of what distinguishes science from other endeavours, and the philosophy of Karl Popper.

In interpreting the books and the scientists' responses on these topics, I will introduce social identity theory to argue that philosophy can be used to rhetorically draw social boundaries and to define social identities around science. This talk surrounding the various philosophical categories however often hides a big variation in actual philosophical opinion, which is set slightly apart from how the philosophy itself is discussed.

*Many thanks to Hasok Chang, Brian Balmer, Berangere Bacquey and the scientists who participated in the study. The research was funded by the Economic and Social Research Council.

*Received by the editors:* 20 January 2009; 12 October 2009.
*Accepted for publication:* 5 March 2010.

Next to being a contribution towards a fuller sociological understanding of how science thinks of itself, this study is also intended as an argument for using the sociological study of the philosophy of scientists for the help of the philosophy of science itself, and for making it relevant to how science is understood—by the public as well as ultimately scientists themselves. It shows how the two disciplines of sociology and philosophy of science can complement each other by using a science and technology studies approach to the philosophy of science by scientists.

I will adopt the convention from science education studies and use "the nature of science" as an umbrella term to cover historical, philosophical and sociological studies of science. The term can be slightly misleading because, as these disciplines have shown, there is no universally accepted definition of the nature of science, and as I will show in this paper, neither is there a universally accepted definition within the scientific community. Thus, when I asked scientists about how they see the nature of science, I was after their own personal perspective about science. I use the term "scientific method" to mean the branch of the philosophy of science that concerns itself with analysing how science is and should be done. I will therefore use the term in a way that recognises that there are many different ideas of what precisely scientific method consists of.

Studies of scientists' philosophies have been done before, although with various aims in mind, using different methodologies and theoretical frameworks, and looking at different philosophical topics in detail. All of this, plus the fact that these studies were made from the perspectives of different disciplines, makes pooling their results and conclusions very difficult.

## 1.1 Public understanding of science and science education

Research in the related disciplines of science education and "public understanding of science" (PUS), has frequently argued for the virtues of teaching philosophy (along with history and social aspects of) science. In the tradition of public understanding of science survey research on scientific literacy, e.g., researchers such as Jon D. Miller argue that an understanding of the nature of science is essential for basic scientific literacy, and the question of "what is science" is usually included in public science literacy surveys (e.g., Miller, 1987). Work in this tradition has come under criticism within PUS as conceptualising the public as simply deficient in scientific knowledge so that the science communicator's job is merely to provide the facts (notably called by Brian Wynne the "deficit model of PUS", cf. Wynne, 1992 for his critique of the deficit model), which neglects the facts that public knowledge of science is contextualised within society, and sometimes even more relevant than the experts' judgements. The traditional "deficit model" preoccupation with the literacy on the nature of science has come under similar criticism, e.g., Bauer and Schoon (1993) argue that Miller's assessment of literacy in scientific method is too heavily biased towards how Miller himself understands it (they charge it for being too Popperian). Miller replied that his idea of scientific method is just that of ordinary scientists. Since his PUS surveys are designed "to measure the level of public understanding of the scientific approach as understood and used by scientists", Bauer and Schoon are missing the point: "The question was not created to gauge the public's views on the philosophy of science" (Miller, 1993, p. 237). This answer of course somewhat begs the question of what scientists really do think about scientific method. Neither Miller nor Bauer and Schoon had an answer to that, and through its shift of focus to contextual models of understanding science, PUS has now largely abandoned the idea of scientific literacy and with it preoccupations of what philosophical conceptions of science should be taught.

That question however has stayed relevant for science education, which has a large body of literature devoted to the practical and theoretical aspects of teaching philosophy and history of science in science education (among many others there are Matthews 1994; 1998; Abd-El-Khalick and Lederman, 2000; Lederman, 2007; Koponen, 2006). Within this tradition of research, there exist also a lot of empirical studies on various groups' conceptions of the nature of science, mostly concentrating on science students and their teachers/educators (Lederman, 1992 for a review of the literature on teachers' conceptions, Driver et al., 1996; Dogan and Abd-El-Khalick, 2008). Less prominently there are also studies on philosophers themselves (Alters, 1997) and lastly scientists and other experts (Osborne et al., 2003; Wong and Hodson, 2009).

### 1.2 Philosophy and history of science

Scientists' philosophical ideas have also been studied by philosophers, both through the thought that their shop-floor insights may help the development of philosophy itself, and because some philosophers think it is reasonable that they should not stray too much in spirit from how scientists think about their subject. Thus Bailer-Jones (2003) has interviewed scientists on their ideas of scientific models, while a research group at Pittsburgh has recently sought to inform philosophical thinking about the gene by asking scientists themselves about how they understand the philosophical issues around the concept (Stotz et al., 2004). Much more informal that these attempts is a philosopher's attempt through his regular popular philosophy column to canvass readers of Physics World on their assumptions concerning realism (Crease, 2001, 2002).

This rather sparse research on contemporary every day working scientists stands in contrast to numerous studies by philosophers that focus on historical case studies (which however usually look at scientists' actions rather than their thoughts) that try to test philosophical theories on science by looking at historical developments. The literature is huge, but well represented by research program of Donovan et al. (1992), or the analysis on how scientists evaluate predictions in Brush (1989).

### 1.3 Sociology of Science

Lastly, scientists' opinions on philosophical topics has been an occasional research subject of sociologists of science. One study that stands out is from Gilbert and Mulkay's (1984) hugely influential book analysing interviews with a group of biochemists. The scientists' talk of Karl Popper was written up as a separate article for a philosophy audience that did not make it into the famous book (Mulkay and Gilbert, 1981). They identified what they call an empiricist and a contingent interpretative repertoire in the way scientists talk about science: the empiricist repertoire is a collection of interpretative phrases and devices scientists use when talking more formally about science, and in which science is represented as logical, rational and following empirical and logical philosophies such as that of Karl Popper. The contingent repertoire by contrast was used more often when scientists were talking informally about science, where it was acknowledged that science has a human and contingent side to it. In the case of their talk about Popper, scientists would, e.g., state that science follows the methodology of falsificationism. At the same time when talking about particular scientists such as their rivals, they would talk about human fallibilities, e.g., that this scientist talked about being a Popperian, while he clearly failed to put that into action. Working from a similar theoretical perspective, Potter (1984) has analysed psychologists' discourse of Thomas Kuhn at a conference he attended. Some other sociological work has analysed scientists' written discourse on philosophy; Sovacool (2005) surveyed astronomy papers for their references to Popper, while Nieman (2000) and Turney (2001) analysed philosophical references in popular science books.

In this paper I will present a study that complements the ones surveyed above, and hopefully add a perspective that combines these three concerns. Scientists learn foundational and philosophical issues about science primarily from other scientists, as became very clear in my interviews. How philosophy gets represented by scientists, what uses it is being put towards, and how that influences scientific thought is interesting from a sociological and philosophical point of view, because it shapes science at the same time as it shapes lay philosophical thinking, and the way scientists believe science should be taught.

### 1.4 Methods

I conducted four pilot interviews based on a convenience sample of physicists and astronomers, in which I tested some prior ideas of how scientists talk about philosophical topics and to find which topics they found interesting and/or controversial. The pilot interviews guided the topics I selected for the main interview study, and directed me to which topics to pay most attention to in the books. The pilot interviews were later coded and analysed together with the main interviews.

After the pilot, I have closely read 30 recently published and acclaimed popular science books and analysed how they represent themes from the philosophy of science in general. Next to building up a picture of how the authors think science differentiates itself from other endeavours, I have also tracked other philosophical themes that have come up in the books most; these were the philosophers Kuhn and Popper as well as the concepts of reductionism and Occam's razor or simplicity as a value in science. I have decided to look at popular science because the genre gives a unique opportunity to scientists for explaining why and how their science was conducted, away from the strict constraints of the technical and textbook literature. Furthermore, because popular science is specifically aimed at explaining science to intelligent non-scientists, it contains a lot of explanations of how science in general works, and this inevitably includes many philosophical observations. Popular science is therefore a rather unique genre for giving us an insight into how the authors view the philosophy of science (as argued by Turney, 2001).

Relevant pages from the books and the transcripts from the interviews were analysed using qualitative data analysis software, Nvivo and Atlas.ti. In order to build up a corpus of books that were unquestionably scientific, I chose from the shortlists of the Aventis prize for popular science (called the Rhone-Poulenc Prize until 1999 and since 2006 the Royal Society prize). To get a selection of contemporary books I selected books from between 1998 and 2004; books not written by scientists and books about mathematics were filtered out (cf. the appendix for a full list of books that I have included in the corpus). The precise definition of who is a scientist for the purposes of constructing the corpus is by necessity slightly vague. I have striven to be as inclusive as possible and include authors who have some experience of conducting science themselves, and have therefore opted to select authors who either have a doctorate in a science discipline (again, trying to be broad with me definitions and thus including psychology as well), or those who have published research in peer reviewed science journal.

Then, 36 scientists were interviewed on the topics that came up in the books, as well as a few more general question about how they themselves have learned about what is science and how it should be done. The scientists were all chosen from university departments of physics, chemistry and biology, about two thirds based in the UK, and a third in Paris. In the sections below, interviewees will be marked by a unique number, their gender and seniority and the country they are based in (a few interviewees had experience of working in both Anglo-phone and French environments, in which case I have marked this as well). The pilot interviews were included in the final analysis and marked as numbers 1 to 4. French scientists were given the choice to hold the interview in French, in which case I will present my own translation in the main text below and provide the original as a footnote.

In the interviews I have asked the scientists to give me their idea of how science works, and what distinguishes science from other pursuits. When a scientist answered merely that it consists of following the scientific method, I have asked them to explain what exactly the scientific method is. I have also asked how they acquired their current opinions (e.g., through tuition, reading philosophy or introspection). Afterwards I asked targeted questions on Occam's razor, reductionism and the philosophies of Kuhn and Popper.

By comparing scientists' views in interviews with how science presents itself publicly in popular works, the study first presents us with a comparison that can ask whether science's publicly visible face is giving us a portrait of science that is consistent with the way ordinary working scientists think about it, though I will not concentrate on that effect on this paper. Second, however, the comparison can highlight for us the way the intended audience can influence the way science is portrayed. Because popular science is highly visible not only to the public but to other scientists, it affords the author an opportunity to be seen the way he or she wants to be seen, and therefore rhetorical considerations about the effect adherence to a particular philosophy can have become important.

Through the decision to perform a qualitative study, this project is not intended to show a representative sample of scientists' opinions (although I have tried to construct my corpus as representatively as possible), but rather to give a perspective of the different opinions that exist within science regarding the philosophy of science. One of the ideas at the beginning was to supplement the study with a quantitative survey, but it soon became apparent that especially abstract topics like those of philosophy can be interpreted so widely that simply counting the number of "Popperians" will not give a worthwhile insight into the thinking of working scientists. The pitfalls of such a survey are well demonstrated by Crease's (2001 and 2002) admittedly light hearted and informal sampling of physicists' opinions on realism which gave us the phenomenal result that 7% of physicists believed atoms were not real, and 3% even thought the earth did not exist. This does not tell us the scientists' interpretations of science. Are these 3% of scientists idealists? We simply don't know.

The analogy that Bauer et al. (2000) give to characterise the difference between qualitative and quantitative research is:

> If one wants to know the colour distribution in a field of flowers, one first needs to establish the set of colours that are in the field; then one can start counting the flowers of a particular colour. (Bauer et al., 2000, p. 8)

This paper is in an attempt to find out the different categories in which scientists talk and write about the philosophy of science, and offer some tentative interpretations of what is going on. Generally when referring to the numbers of books, or interviewees who responded a certain way I will use qualitative terminology such as “some”, “a few” or “most”. Giving precise numbers of the number of occurrences of particular codes even in a fairly large qualitative corpus is appropriate only in limited circumstances. Very often, e.g., when it came to assessing how many scientists agreed with Popper, there are many borderline and indeterminate cases so that giving precise numbers can be misleading (cf. also Hammersley, 1996, p. 161 ff. for a discussion on the use of quantitative terms in qualitative research). Many comments also came up within the free-flowing conversational format of the interview, and some conversations covered ground not covered in exactly the same way by others. Therefore the numbers that I will provide should be interpreted with some caution.

## 2 How philosophy is used

### 2.1 Philosophical asides: philosophy as authority and boundary marker

Almost every single popular science book had at least one comment, phrase or even paragraph on what is science, or how it works or should work. Popular science books are often an account of what scientists have found out. It is natural to accompany these accounts by outlining how things were found out to work like that, and why that way of finding things out was so persuasive. One kind of comment is that of a more general philosophical discussion on what counts as good evidence, when to abandon or adopt a theory or hypothesis, or what sets science apart from other endeavours where knowledge is not so secure, such as (according to the tastes of the author) sociology, psychology or theology, and also what sets it apart from fraudulent, pseudo or fantastic science. These accounts are usually longer (in some cases up to chapter or even book length), and often feature specific pet philosophers (usually Popper and Kuhn) or philosophies (such as falsificationism, reductionism or Occam’s razor.

The most pervasive category of philosophical comments however is the smaller aside that can appear in almost any context in popular science books. They are generally very short and in a way merely shift the appeal to authority that any presentation of facts rely on in popular science, to an appeal to authority that "this is just how things work in science". Instead of explaining how science works, they tell us how science works. Nieman (2000) analyses similar comments in his characterisation of the uses of philosophical remarks in popular physics. Nieman discusses what he calls "pithy" philosophical definitions that scientists give in their popular accounts as a kind of rhetorical boundary work (Gieryn, 1995), and that in popular science "discourse on the meaning of science is more concerned with the defending or capturing of territory than exploring the metaphysical subtleties of knowledge about nature" (Nieman, 2000, pp. 167–168).

Pithy comments, where something is shown to be good science because it conforms to the norms of science, occurred very often, whatever the author thinks that is: it is falsifiable, verifiable, it predicts things, is based on meticulous or rigorous testing, observing, peer reviewing. The mechanisms of that method are not discussed further, it suffices to show that the science in question conformed (or the pseudo-science failed to conform) to what the author holds as good scientific practice, e.g., when an author wanted to show "new-age dreaming" as not being science because it fails Occam's razor:

> The best theories are rendered lean by Occam's razor, first expressed in the 1320s by William of Occam. He said, "What can be done with fewer assumptions is done in vain with more." Parsimony is a criterion of good theory. With lean, tested theory we no longer need Phoebus in a chariot to guide the sun across the sky, or dryads to populate the boreal forests. The practice grants less license for New Age dreaming, I admit, but it gets the world straight. (Wilson, 1998, p. 56)

In an even pithier aside to scientific method, which is much more typical because it makes only a vague allusion to the philosophical thinking behind the science, Sapolsky discusses a sociobiological hypothesis about the value of kidnapping in baboon society.

> The alpha male is about to pound you [i.e., a threatened baboon]. You don't grab just any kid, you grab someone who he thinks is his kid. Mess with me and your kid gets it. Kidnapping, hostage taking. Pretty clever. The idea generated all sorts of predictions. (Sapolsky, 2001, p. 100)

The crucial part here is that the idea generated predictions, which is one of the more frequently voiced attributes of a good hypothesis, and Sapolsky goes on to argue that these predictions were then put towards the evidence to see if they supported the sociobiological hypothesis:

> The sociobiological model has been supported only to some extent by the data. Appendices have been added on to the theory. ... The debate rages on, keeping primatologists off the dole. (Sapolsky, 2001, p. 100)

Sapolsky here reveals a vaguely hypothetico-deductive stance, where it is important for a hypothesis to predict things which will then in turn be checked by experiment or observation. Sapolsky finishes this section by admitting that the available data has not yet been able to settle the dispute, with a humorous but resigned verbal shrug.

Although it is possible to characterise to an extent what the prevailing philosophical opinions were among the books, the context in which most philosophical remarks were made were often as a rhetorical device for quickly demonstrating why something being discussed is not proper science, without the need to go into particular details. These comments do not necessarily add up to a coherent or complete view on how science works. Nor do they necessarily represent what the author thinks is the most important distinguishing feature of science: The actual philosophical point may have been chosen to show that bit of science being discussed in a most favourable light (or the other way around for pseudo-science), and the highlighted bit of philosophy may therefore have been chosen for convenience.

There were no real equivalent to these philosophical asides in the interviews, because I asked the question of what is science directly. However, many scientists had a ready answer to the question, that they gave without hesitation but which was considerably qualified during the later discussion, suggesting that here philosophy again fulfilled a rhetorical function as an appeal to authority which was taken as given, instead of being questioned. This was particularly the case for the philosophy of Karl Popper, which will be analysed in more detail in the following section.

### 2.2 Philosophy as an identity: The case of Popper

In social identity theory (Tajfel, 1981; Tajfel and Turner, 1986; Hogg and Abrams, 1988), which has by now become a standard tool to make sense of group interactions within social psychology (cf. Brown, 2000 for a critical review) , individuals within a group enhance their own self-esteem by self-categorising themselves as conforming to group norms and values, which are usually perceived as positive and desirable attributes. In the process of categorising ourselves we tend to accentuate those aspects of our own attributes and values which conform with those of our group (the ingroup), while we simultaneously downplay those that are in conflict with it. At the same time, when considering the attributes of people outside of the group (the outgroup), we tend to accentuate the negative aspects and downplay the positive ones and those they actually have in common with the ingroup.

Social identity theory has explicitly been formulated primarily to explain stereotyping and discriminative behaviour (as explained in a biographical note by Tajfel, 1981), but also accounts for the more positive aspects of ingroup identification, and the discursive and rhetorical practice with which identification is negotiated. In experimental settings social identity theory has a amassed a considerable amount of evidence in its favour though it still lacks in applications to real life case studies (as argued by Huddy, 2001).

Probably unsurprisingly, the one philosopher that was mentioned most often in both books and spontaneously in the interviews, was Karl Popper. Popper was mentioned spontaneously in answer to my first question on what distinguishes science by seven interviewees, and only seven interviewees said that they have never heard of him. Scientists' allegiances to Popper were however curious: the reason that I introduced social identity above, is that Popper seems to have become a group norm for science, so that following Popper has become a value that many scientists think they fulfil by virtue of belonging to that group. Of the eight books that mentioned Popper, only one (Mayr, 1997) was negative towards him, though he was negative towards all philosophers. Through the accentuation effect, and the fact that as an abstract philosophical set of statements Popper's philosophy is already open to a fairly wide interpretation, it has become possible for a scientist to identify with Popper's philosophy, almost regardless of his/her actual philosophical opinion.

This identification effect was particularly visible in the books. Popper (or falsificationism) would, e.g., be mentioned in a pithy, authoritative way as outlined above, where the mere mention of a scientific episode following Popper was seen to be enough to show that something is scientific. The natural historian Richard Fortey, e.g., backs up his discussion on ad hoc explanations by remarking that they are

> anathema to all those brought up with the scientific and philosophical rigour of Karl Popper and Ernst [sic] Nagel. Scientists do not trot out ad hocs the way a magician pulls flowers out of a top hat; it is not considered proper behaviour. (Fortey, 2000, p. 241)

Note also how Fortey includes the for philosophers slightly contrary stances of Popper and the post-positivist philosopher Nagel as both exemplifying good scientific thinking.

The conflation of Popper and the logical positivists went even further with Stephen Hawking:

> Any sound scientific theory, whether of time or of any other concept, should in my opinion be based on the most workable philosophy of science: the positivist approach put forward by Karl Popper and others. (Hawking, 2001, p. 31)

Here Hawking does not actually interpret positivist philosophy by widening it to include Popper's falsificationism, instead he seems to describe a fairly consistent logical positivist outlook, and then thinks Popper shared it:

> If one takes the positivist position, as I do, one cannot say what time actually is. All one can do is describe what has been found to be a very good mathematical model for time and say what predictions it makes. (Hawking, 2001, p. 31)

Even authors who were very knowledgeable about Popper's philosophy, and who wrote about him at length, such as David Deutsch (1997) showed that it was possible to identify with Popper while at the same time criticising his philosophy. After all, there is no rule about how much we have to actually agree with Popper in order to be Popperians. In one chapter he sets up a fictional debate between a "crypto-inductivist" and himself about the validity of Popper's philosophy, and inductivism in general, which deserves a slightly longer quotation:

> CRYPTO-INDUCTIVIST: ... You make a careful distinction between theories being justified by observations (as inductivists think) and being justified by argument. But Popper made no such distinction. And in regard to the problem of induction, he actually said that although future predictions of a theory cannot be justified, we should act as though they were!
>
> DAVID: I don't think he said that, exactly. If he did, he didn't really mean it.
>
> CRYPTO-INDUCTIVIST: What?
>
> DAVID: Or if he did mean it, he was mistaken. Why are you so upset? It is perfectly possible for a person to discover a new theory (in this case Popperian epistemology) but nevertheless to continue to hold beliefs that contradict it. The more profound the theory is, the more likely this is to happen.
>
> CRYPTO-INDUCTIVIST: Are you claiming to understand Popper's theory better than he did himself?
>
> DAVID: I neither know nor care. The reverence that philosophers show for the historical sources of ideas is very perverse, you know. In science we do not consider the discoverer of a theory to have any special insight into it. On the contrary, we hardly ever consult original sources. They invariably become obsolete. (Deutsch, 1997, pp. 156–157, original emphasis)

In the interviews, however, while Popper was indeed very well recognised, that alone did not mean that his philosophy found much favour.

Some scientists had specifically built their whole understanding of science around Popper, though that was a fairly rare reaction. One scientist actually decided that Popper had in fact described science very well, after having heard negative opinions about Popper in his own undergraduate philosophy education:

> [In the philosophy course] Popper was a dirty word [laughs]. Well, that's how I remember it, I mean [. . .] I think the general idea was that science is more complicated than that. And that a lot of it is social influences and so on and so forth. But now I've been practising science quite a lot longer than I had then, [. . .] you know, clearly falsification is absolutely key, if [inaudible] going to have to test hypotheses, then falsificationism is what a lot of science is about. (12 Senior, Biology, Male, UK)

Very negative reactions towards Popper however also occurred. During a discussion of science in general during one of the pilot interviews, this scientist showed a lot of dissatisfaction with Popper:

> I think Popper's rejection of induction as a means of developing scientific theories and models is just crass in the extreme. (1 Senior, Physics, Male, UK)

Most reactions to Popper however were positive as well as negative. While Popper himself was assessed positively, most of those who had heard of Popper and had mulled over the philosophy of falsificationism applied to their own day to day scientific life, decided that there has to be more to science than just falsificationism, and that things like verification and induction have to have a role as well in any philosophy (20 interviewees in total).

But there can be a lot of similarity between agreeing with a philosophy and therefore in a way identifying with it, and on the other hand rejecting it while holding a fairly similar opinion. This is often manifested by followers of Popper still ascribing a large role to verification as well as falsification in science.

> Scientific method is that within some system you make hypotheses, you make testable hypotheses, you test them, and you keep the ones that are verified, and you throw out the ones that are falsified. (32 Senior, Physics, Male, France/En)

This scientist was very aware of Popper, admitting though that he does not know much of his work. Asked whether he accepted falsificationism as a philosophy, he replied, laughing: "Nothing else to say. I buy that one!". This shows that even when Popper has clearly influenced a scientist's thinking towards science, his precise teachings are not necessarily taken over wholesale. In this case it is, as the scientist admits himself, because he does not know that much about Popper's philosophy, and has only taken on board those aspects of it that he heard being discussed informally and those he agrees with.

The role he ascribes simultaneously to verification and Popper's philosophical authority is rather fascinating. Having explained a particular case from his own experience where he thinks to have verified something, he goes on to imagine Popper's response:

> So I think for me, from a more or less a logic layperson's point of view, we verified the hypothesis [...]. I guess Karl Popper is going to tell me that it could be many other things because we haven't tested every possibility [laughs]. (32 Senior, Physics, Male, France/En)

While the logic of science according to Popper may dictate rejecting verification, actual science manages quite well with it. Through this intervention of the imaginary Popper, this scientist manages both to defend the way he does his science, and yet defer to the philosophical authority of Popper, to which he interestingly, if mildly sarcastically, subjects his own scientific work. Regarding philosophy of science and logic, he regards himself a layperson.

I have argued above that some of the reason that popular science authors like Deutsch are prepared to identify themselves with Popper's philosophy while still disagreeing with it to some extent, may signify the adoption of Popper as an identity marker which shows the authors conform to what they think is proper scientific attitude, i.e., supporting Popper. Scientists who believe that Popper embodies rational and scientific thought, such as Fortey, will believe that they follow Popper's philosophy as long as they also believe that they are doing their science properly (as most scientists would obviously do). Discrepancies between the philosophy of Popper and the scientists' actually held philosophy can very easily be explained, either by the scientist having only an incomplete understanding of what Popper stood for as in the case of Hawking for whom Popper becomes a logical positivist, or by arguing that Popper would probably have agreed, as in the case of Deutsch.

In the interviews this identification is evident as well, though somewhat weaker, with respondents who reacted very positively towards Popper, but then also disagreed with his philosophy, or at least argued that there must be more to science than just falsification. Some of them also argued, similar to Deutsch, that surely Popper would have agreed with them, or that he did not really mean it like that. Throughout the interviews the interviewees also often qualified their remarks by saying that they were not well qualified to speak on these philosophical matters, which in some sense also gives the authority to speak of such matters back to the philosopher.

By these mechanisms, the generally (though by no means universally) positive attitude towards Popper hides a great variation in the way scientists thought about science, and the next section will try to chart and categorise these views.

## 3 Scientists' philosophical opinions on science

As I have argued, identifications with particular philosophers or philosophies by scientists may not necessarily translate into accepting them wholesale, so any survey of scientists' actual lay philosophies must try to look deeper than that. In the books that was naturally very difficult, because I couldn't ask direct questions. However, the interviewees have, despite the very limited amount of official philosophies they held to, shown a very wide range of opinions of how science works, and while this alone will not be surprising, I have found that these opinions map out differently than discussed in most philosophy textbooks, and their popular science representations.

The three overarching themes are familiar: Science is hypothetico-deductive, science is inductive, and science is a social enterprise. These however are discussed on slightly different terms than is usual in philosophy.

### 3.1 Science is hypothetico-deductive

Scientists most often, both in the interviews and as far as can be seen from the books, held that science works by proposing hypotheses, checking what their consequences are, and then proceeding to test them. This was the most frequent idea about science in the interviews. It also of course, maps onto the discussion on Popper above. Just as was the case with the books, there were several ways the respondents voiced the idea. Followers of Popper, e.g., unsurprisingly, emphasised the falsification aspect of the testing (ten in total), while many others spoke of verifying or even of both verifying and falsifying (ten), or that science is distinguished by being testable in some unspecified form (twelve). Others (ten, again) emphasised the idea that science predicts phenomena, without necessarily mentioning that those predictions will be put to test, though that was usually implied.

However, within a sea of comments such as that what distinguishes science is that it is testable, there were also some expressions of disquiet. First of all, even the idea of theories, and research that is driven by hypotheses was questioned:

> Respondent: I'm not entirely happy with theories, that, the business of hypothesis driven research, I find a little bit uncomfortable sometimes, because there are other ways of doing good research.
>
> Me: Such as?

> Respondent: I like the, the "this is an interesting question, let's [inaudible]" approach. "I wonder what would happen if . . . " (8 Senior, Biology, Female, UK)

The complaint that there is more to science than just theory testing, was made very often (also often in the discussions following falsifiability discussed above). However, though this reservation was often voiced during the discussion on Popper, some scientists, like the one quoted above, have even brought this point forward within the initial discussion of what science is, without any prompting of mine. This conscious counter-positioning of course also signals that this scientist knows that the dominant scientific discourse on method follows hypothetico-deductivism.

### 3.2 Science is inductive

There were also comments that emphasised the accumulation of facts in science (seven interviewees said that science is a collection of facts or generalisations; twelve emphasised observation and/or experimentation). People who made these remarks always pointed out that science should of course not only consist of collecting facts or merely observing, but that a lot of characterisations of science miss out on this rather fundamental aspect. Therefore, for some scientists, induction had an important role to play in science. For example one biologist argued that an important part of science was laborious fact-finding which has to be done before hypotheses can be constructed at all.

> I think this aspect of science also this kind of accumulative . . . accumulation of limited, but somehow useful, knowledge is an important part of science. (36 Senior, Biology, Male, France)

Very close to the idea that science is about collecting facts, is the inductive argument that science arrives at conclusions by generalising from the facts it observes:

> That, too is a thing common to all scientists, that from a particular thing we try to get a generality out, I think. (29 Early Career, Physics, Male, France)

It is worth pointing out that people who argued for science being the accumulation of facts never argued that that is all science is, just as it was usually the case that scientists who argued for hypothetico-deductivism, even those that strongly identified with Popper, argued that there is more to science than that. In this sense inductivists were quite close in opinion, though not emphasis, to those who pointed out that science is not merely the collection of facts, but also has other qualities. This, interestingly, did not come out in the books as clearly as it did in the interviews.

### 3.3 Science is a social enterprise

Scientists almost always acknowledged that science is a human endeavour, with all the messiness and contingencies that entailed. The influence of the social side of science on scientific knowledge was however not necessarily portrayed as negative, instead it was seen as an important and central part of science.

Most scientists held that science conforms, or should conform, to Merton-style social norms (Merton, 1973); it was often stressed that science is objective or open minded. Thirteen interviewees explicitly mentioned objectivity, eight saw science as characterised by "open-mindedness" and honesty, fifteen mentioned rigorousness and scepticism.

> what [my chemistry school teacher] used to say, "it is a scientist's bounded duty to hold his theories lightly and give them up graciously when proven else wise by somebody more ... clever". Or something like that, I mean that's the wrong words, but that's the gist of the quotation". (8 Senior, Biology, Female, UK)

This was however also often linked to an admission that this really is only an ideal, and that scientists are often fallible. Next to the comments on the rationality of science, there were plenty of admissions (eighteen) that real life science is usually much messier than that. There was a general feeling that the human side of science is very much an inseparable part of science, whether you think it is a good thing or whether you think it is regrettable but unavoidable. Even things like the personal attachment scientists have for their pet theories (mentioned seven times) is in some circumstances good thing, rather than always hindering progress as Popper would have argued:

> scientists are particularly prone to getting attached to something which objectively they might not do. And I think this is because as a scientist you need to have a good intuitive feel, and that's important for inventing hypotheses. And so, you learn to have maybe too much confidence in your intuition, which can get into the way of being objective. (23 Early Career, Physics, Male, UK)

Many more comments on the social side of science were made in the context of discussing Kuhn's philosophy later in the interviews. In these discussions the social sides of science were very often seen as necessary parts of science, and even followers of Popper agreed that Kuhn may have painted a much more realistic picture of science, warts and all.

I would argue that these topics are not necessarily the way philosophers themselves divide their subject into. On the one hand, hypothetico-deductivism is such a broad area that its several different varieties, such as falsificationism, positivism or Bayesianism were and still are fiercely contested, whereas for the scientists in my study the most important aspect of science was the basis they all shared, while the details were mostly seen as less important. On the other hand the strict division that philosophers have drawn between the empiricist/logical aspects of science and its social sides, often with the approval of science warriors, does not seem to be held widely by the scientists. Like the subjects in Gilbert and Mulkay's study, the scientists often talked about science in a "contingent" way, however (maybe because I asked them directly how that fitted in with their other views) I have heard very often that these two sides of science are both necessary for it to function, and so there was no obvious separation between the two interpretative repertoires, as Gilbert and Mulkay (1984) have found.

## 4 Lessons

Where scientists' representations of philosophical topics and the nature of science come from is also crucial to how scientists understand them. The education that most scientists told me they received on the nature of science was informal, based on picking up "tacit" knowledge (Polanyi, 1958; Collins, 2001), and mostly conveyed to them by other scientists. Otherwise, the context in which philosophies are picked up varied enormously from self-motivated reading, to attending lectures and even whole lecture courses on philosophy of science, run variously by scientists or philosophers. In each of these contexts philosophy gets communicated differently, and that reflects how the philosophies get interpreted.

Since scientists' representations of philosophical topics are being shaped more by other scientists themselves, and because they fulfil social psychological and rhetorical functions of identity and boundary markers, they can develop a particular dynamic. Hence, while they are certainly not naive, scientists' understanding of philosophy becomes fundamentally different to the way philosophy is understood by philosophers. The examples I elaborated in this paper illustrate the point: Popper has become an iconic figure for scientists that represents what it is to be scientific, even when he no longer commands much respect within the philosophical community. However, scientists' interpretation of what Popper stood for, and their interpretation of what it means to be Popperian is very much unlike the way philosophers interpret Popperianism. Also, when they talk about their own opinions on how science works, scientists divide the problems up in different ways from how they are discussed in philosophy, where even scientists who identify with Popper are comfortable with also holding other philosophies that are directly at odds with Popper.

For this reason—that scientists quite rationally hold several philosophies that are traditionally seen as conflicting—a simple survey of how many scientists are Popperians, and how many are Kuhnians would have given very spurious results, and it becomes clear that the way philosophy is used, thought and talked about needs to be sampled first before we can arrive at what meaningful questions to ask in the first place.

From the point of view of general science studies I believe that the sociological study of how scientists think about their activities philosophically is interesting in its own right, as it contributes to a further understanding of how science and scientists work and think about their work, and therefore elaborates on the social working of science. The philosophical reflections of scientists and how that relates to the philosophical issues debated by philosophers themselves and the discursive work philosophy performs in scientists' boundary work—these areas are generally understudied.

Studying the ways in which scientists talk about the philosophical foundations of their activity is also important from a practical view as it allows the social scientists studying science themselves to understand what scientists think are the important issues, how they are thought about and represented and what uses they are put to. This helps in understanding wider, more general, issues in science studies, as it can then inform a possible understanding of what happens when the communication between scientists and sociology of science breaks down. An example is the philosophical misunderstanding between sociologists and scientists during the science wars. Understanding the representations of philosophy by scientists can highlight where the science wars hinge on different interpretations of and significances attached to fundamental philosophical ideas. There are also some specific issues particularly in the social study of popular science which this study highlights, though this may not be a lesson as such, but rather a point to bear in mind when studying popular science. Regarding the differences between the scientists and the popular science authors in the exposition of philosophical topics, while it may in the end not be a big problem for philosophers, there are problems for popular expositions that make liberal use of philosophical asides, or philosophical topics such as Occam's razor or Popper's philosophy as a demarcation tool, or that use of philosophies as an identity marker which essentially talks to other scientists rather than the public. In light of the contested nature of philosophical topics in popular science, it is a pertinent question to ask whether the epistemologies as portrayed in popular science are giving us a consistent and realistic portrait of science.

Finally, the lesson for philosophers is that through their own social representations of philosophy, scientists have developed their own ways of talking and thinking about philosophical topics. If the formal relationship between scientists and philosophers deteriorates to the point that the philosophical opinions that scientists will inevitably have of their subject are drawn almost exclusively from among the philosophical discourse of other scientists, then philosophy of science may become slightly redundant, from a scientist's perspective. What is worse though is that in that case the philosophical discourse on philosophical topics and the scientific discourse on exactly the same topics will diverge so that the same terms and concepts will acquire different and confusing meanings. This can already be seen with reference to the different categories in which scientists think about philosophical topics in this study. There is already a movement within current philosophy of science that seeks to address the issue of philosophising on actual scientific practice, with the recent set-up of the Society for the Philosophy of Science in Practice. Although this approach addresses the relevance issue of philosophy of science, it still needs to monitor not only the way scientists practise science, but also the way science thinks about itself. Otherwise, while possibly the contents of philosophy of science can be made relevant to scientific practice, the way scientists understand that philosophy will be different to the way the philosophers understand it. Ultimately, whether philosophers like it or not, scientists will philosophise about science on their own terms, and if philosophy wants to participate in the discussion it must at least know what the philosophical issues are that scientists find relevant and interesting, but also how and in which categories they talk and understand philosophy, and when and under what circumstances philosophical topics become issues of identification and boundary work on top of their philosophical message. It is in identifying and keeping track of these types of issue that I believe sociological investigations of scientists' discourse on philosophy can make a contribution to the philosophy of science itself.

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