Reflections on philosophy of nanoscience from nanoscience practitioners

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In this paper we present findings from an experiment involving both scientists working at the nanoscale and philosophers interested in this emerging field of research. Early career scientists working at the nanoscale were asked to read, discuss and debate two examples of philosophy of science that had been written with a specific focus on nanoscale science and technology. The papers that our participating scientists were asked to read were one by Jan Schmidt (2004) and one by George Khushf (2004). These papers are interesting for comparative discussion because although both draw on similar cases to make their arguments, Schmidt argues that nanotechnology represents a new form of reductionism, while Khushf argues that the field represents a shift towards more systems-based approaches of understanding and acting. The initial aim of this experimental exercise was both to create a space for discussion and reflection, and to investigate the scientific literacy of emerging works in the philosophy of nanoscience. Interestingly, interdisciplinary interaction during the exercise saw unexpected topics of interest and discussion emerge. In discussing the two articles, the scientists participating in our exercise highlighted a range of questions that not only related to the scientific content of the philosophers' arguments, but also to the way in which they conducted and presented their research. This exercise demonstrates the added value and richness that can come from interdisciplinary interactions across the social and natural sciences and from iterative discussions across theory and practice, especially when focused on emerging fields of research such as that of nanoscience and technology.

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> Instead of such an overly general and unhelpful notion of the scientific enterprise, we should look at what is actually taking place within the disciplines, at the boundaries between the disciplines and in the trading zones where knowledge and technology are produced […] there are opportunities for establishing a rich dialogue between the sciences and the humanities. (Khushf 2004: 22)

Context

The origin of the concept of nanoscience and -technology (nanoS&T) is usually traced back to a famous talk by Richard P. Feynman «There is plenty of room at the bottom» (Feynman 1959), in which he argued that the laws of physics do not prevent us from manipulating matter at the nanometer scale, that is, manipulating matter atom by atom. The word «nanotechnology» itself, however, was coined by Norio Taniguchi in 1974 (Taniguchi 1974) and was later popularized by Erik Drexler (Drexler 1986). Despite it now being actively used in many branches of the natural sciences, as well as in policy statements, funding programs and social science research, it remains difficult to find a clear definition for the concept of nanoS&T that is generally agreed upon (Kjølberg & Wickson 2007). Explicit definitions often center on the (nanometer) size of the objects under study and the novel properties occurring at this scale. For instance, Roco (1999: 1f) defines it thus: «Nanotechnology is concerned with development and utilization of structures and devices with organizational features at the intermediate scale between individual molecules and about 100 nm where novel properties occur as compared to bulk materials.»

Interestingly, as large investments are being made in nanoS&T research, some of this money is also being allocated to ELSA research[1] – research on the ethical, legal and social aspects of nanoS&T development. Following the public concern, debate, and in some cases open rejection of genetically modified organisms, the perceived need for ELSA studies of emerging technologies was heightened dramatically. As investment in nanotechnology follows these developments in biotechnology, there is a very strong sense that lessons should be learnt from the controversies that have arisen in this area, and as part of this, that social and ethical research should be carried out in advance, or «upstream», in the process of the nanoS&T's development (Doubleday 2007; Macnaghton et al. 2005). The primary aims of this «upstream» engagement can be seen as either to actively direct technological trajectories in socially desirable directions, or to more subtly do so by engaging scientists in reflections on social and ethical dimensions of their work.

In this paper, we describe an engagement exercise in which early career researchers in the field of nanoscience were asked to read and discuss two examples of philosophy of nanoS&T literature.

Research aim

The exercise reported in this paper was motivated by two key interests. The first was a general interest in engaging practitioners of nanoscience in reflections on social and ethical aspects of their work. The specific design of the exercise was, however, also strongly influenced by a second interest in investigating the «scientific literacy» of some of the emerging philosophical literature on nanoS&T. While research on attitudes to nanotechnology often includes questions about the general public's knowledge of nanoscience (e.g. Bainbridge 2002, Cobb & Macoubrie 2004; Scheufele & Lewenstein 2005), there appears to be no similar research on the level of knowledge of philosophers writing about the field. Our second interest was therefore in how accurately informed nano practitioners thought philosophers of science were in their representations of the field. In this sense, we wanted to use philosophy of science writings to stimulate scientists to reflect on their own work, but we also wanted to use the scientists and their work to investigate the accuracy of the philosophical writings. While this dual aim guided both the choice of articles and the reading/discussion instructions given to the scientists (outlined below), it is important to note that the outcomes of this interdisciplinary exercise shifted the issues of interest and generated unexpected topics of discussion. This point will be more clearly illustrated as we present the results of this exercise and discuss our conclusions.

Research method

The engagement exercise documented in this paper was conducted as part of a PhD course titled «NANO: Science, Technology and Ethics», collaboratively coordinated by the University of Bergen and the Norwegian University of Science and Technology (NTNU) in Trondheim. The course took place over a week-long period in August 2007, and was primarily directed towards natural science PhD students whose research was in some way related to the nanoscale. In addition to the natural science students, the course also attracted participation by two students writing dissertations on ethical aspects of nanotechnology, as well as a representative (with scientific training and qualifications) from an institution that advises the Norwegian Government on technological issues. While the three members of the teaching team were academics currently working in the fields of philosophy and/or science and technology studies, all had a masters or PhD in a natural science discipline. One afternoon of the week-long course was dedicated to the exercise we describe in this paper.

The research approach of the exercise was to first ask the participating scientists to read two specifically selected examples of philosophy of nanoscience and to make note of their individual thoughts, comments and reactions while reading these papers. During the course, they were then assembled into small multidisciplinary groups to discuss and collectively reflect on the selected literature. Three small discussion groups (of around five participants) were each moderated by a member of the teaching team, while one of the students writing on ethical aspects of nanotechnology was asked to circulate between all three groups to provide an overview. For these small group discussions, the participants were asked whether the descriptions resonated with their work and experience as nanoscientists, and whether they thought the writings were accurate, informative, informed. As a final stage, the three small groups were gathered in a plenary session to discuss the ideas and share their insights. Both the small group discussions and the plenary session were (audio) recorded for future analysis and further reflection and all participants gave oral consent for this to occur.

The two articles that were selected as the focus for discussion were those of Schmidt (2004) and Khushf (2004). These articles were specifically chosen because of their interesting combination of similarities and differences. They both appear in the first anthology of writings focused on social and ethical aspects of nanoS&T (Baird et al. 2004), both draw on a well-known report by Roco and Bainbridge (2002) to support their arguments, and both converge on a position that reductionism has severe limitations as an approach to knowledge. While these similarities make good grounds for comparing the articles, what they conclude about the field of nanoS&T makes them perfect to contrast. In short, Schmidt (2004) argues that nanoS&T development represents a new form of reductionism (technological reductionism), while Khushf (2004) suggests that this emerging field is actually advancing a systems theoretic alternative to reductionism. What is particularly interesting about these two articles is that while they draw on the same data for analysis, they make radically divergent claims about the philosophical foundations and nature of nanoS&T. As almost diametrically opposed conclusions arise from analysis of the same field (and in this case largely the same document), it was thought that these two papers provided particularly rich material for stimulating discussion and were particularly interesting to investigate in terms of scientific literacy.

After the exercise had been completed in terms of the scientists' direct discussions and reflections, the analysis that is documented in this paper occurred in four key stages. Firstly, two of the course participants wrote essays specifically focused on comparing and contrasting the two articles, drawing on both their own ideas and the discussions that had taken place. The designer of the exercise (the first author of the present paper) then used these essays to begin documenting the issues of interest that arose through the exercise and invited the essay authors to collaborate on the present article. The second layer of analysis occurred when the first author revisited the recordings taken during the exercise (as well as the notes taken by the student that circulated among all the groups) in order to continue mapping the overall themes of discussion and to then begin identifying recurring topics. In listening to the recordings, notes were taken on all points of conversation in all three small discussion groups and the plenary session. These were then compared in order to identify overlapping themes of interest, recurring topics of discussion, and places where common positions were expressed. To check the accuracy of the identified overlapping themes, a fourth author was invited to coauthor the paper. The inclusion of this author meant that in addition to the exercise designer, a participant from all three of the different discussion groups was involved in calibrating the analysis.[2] The third important stage of analysis occurred when the overlapping themes of interest were checked, discussed, agreed upon, elaborated upon, and written up by all coauthors on this paper. The recordings were then listened to a second time to confirm the accuracy of the identified overlapping themes and to transcribe the direct quotations that appear in this paper.

Results and discussion

This paper will now progress by describing in a more detail, the content and arguments of the two selected articles, as well as the results of the exercise in terms of the overlapping themes of discussion. We will begin with the article by Khushf (2004).

What did Khushf say?

In a recent article, George Khushf (2004) discusses the role of reductionism in nanoS&T and claims that new developments in the field necessitate the development and adoption of a systems theoretic alternative. Khushf (2004: 22) outlines his argument, and that of other convergence advocates, by describing the components as follows:

> (1) that there is an old approach to science and engineering, in which knowledge is fragmented, pure and applied domains are distinct, and a reductionist approach is taken to the relation between disciplines; (2) that new research and tools in science, especially those associated with the nano-scale science and technology, lead to a convergence of disciplines, a holistic approach to knowledge, […] and (3) that hierarchical, systems theory can provide the framework for the integrated paradigm needed for this new science.

Within what Khushf (2004) calls «The Old View of Science» or the «the grand project of reduction», there are four major features or assumptions about the nature of science that he highlights as characteristic:

1 A belief in the existence of a hierarchy of nature and of scientific disciplines, i.e. «chemistry builds on physics, biology on both, and the human sciences (psychology, sociology, economics etc.) build upon the biological» (Khushf 2004: 5)
2 A belief that the scientist performs his or her work as a neutral or «objective» observer
3 The idea that every discernible effect in the world has a cause, the causal relations for which are described by laws and the «mechanism» involved. «Ultimately, higher level phenomena are to be explained in terms of lower level components and their interaction» (Khushf 2004: 6)
4 The position that there is a distinction between pure and applied domains, where the former is viewed as independent of individual interests and values.

Although all these points are, in Khushf's opinion, highly problematic, he recognizes that this «old view» of science and the model it represents have been helpful for structuring scientific investigations. However, what Khushf claims is that due to the new developments in the nanoscale regime, this model is «no longer helpful» (Khushf 2004: 8). Khushf argues that a new model of science is needed to take account of the unique features of nanoS&T and the complexity it represents. The features described as unique to nanoscience are: the bridging of quantum and classical domains, the merging of bottom-up and top-down approaches, the symmetrical integration of physics, chemistry and biology, and the blurring of lines between pure and applied domains.

Given the way the claimed features of nanoS&T challenge the «old view» of science, Khushf suggests that a new model of science is needed, and that one based on a systems theory approach would represent the appropriate alternative. Some of the characteristics sketched by Khushf (2004) for the claimed systems theoretic alternative include:

1 In addition to the «part-to-whole» explanations inherent in reductionism, «whole-to-part» explanations emerge as complementary for the explanation and understanding of natural phenomena.
2 Iteration (between theory and experimentation, and between pure and applied considerations) emerges as a scientific method, transcending both pure deductive and inductive approaches.
3 Scientists under a systems theoretic model do not claim to be objective but rather are much more reflectively aware of the way in which their interests and values shape their research.

What did the nanoscientists say?

Much of Khushf's article is dedicated to describing and critiquing the model he describes as «The Old View of Science». In the paper, he acknowledges that many scientists and philosophers might be skeptical of the claims he makes. However, our exercise raised some additional issues that were not explicitly referred to in his article. The first of these was that some of our participating scientists, who actually agreed with the content of Khushf's description, disagreed or were «provoked» by the way in which his description was presented. Describing a particular view of science as «nineteenth century», «old», and having «outmoded assumptions» was seen as provocative, particularly for those who saw themselves still operating according to the beliefs described: «I was a little provoked by Khushf's suggestion that scientists have a method of thinking from the 1800s [...] but even though I was provoked, I think much of what he said is true.»* (Participant 1, Department of Biomedicine). In a sense, it was a problem with the linguistic implication that they were not doing «modern science»: «I did not feel comfortable with that label [...] I think he has a very simplified model of how scientists work, that they are stuck in the 19th century with a strict hierarchy of organization. Modern scientists as I know them are more pragmatic and not so focused on this hierarchy.» (Participant 2, Department of Mathematics). Some of the participants in our exercise also specifically chose to point out that the concept of «an old versus a new view» did not adequately acknowledge the constant change that they felt existed in models and methods of scientific practice: «I tend to think that science is always changing a little bit so old view/new view ... I am not sure it is really an accurate way to look at it.» (Participant 3, Department of Physics and Technology). It could, in a sense, be argued that by talking about an «old» versus a «new» view, Khushf was perpetuating an image of linear causality that he was trying to critique as flawed.

This article also generated discussion about the pragmatics of science as a research practice versus idealized images of science as knowledge. While all participants seemed to agree that reductionist approaches to knowledge have limitations, limitations that become particularly relevant in certain areas of investigation, not all were prepared to accept that this meant that reductionism could not continue to serve a useful or helpful heuristic role, as suggested by Khushf. In talking about «general models of science», many felt that reductionism remained an important heuristic for the pragmatics of carrying out research: «Reductionism has been necessary ... it is a useful concept ... to understand a complex thing it is very very helpful to take it apart first.» (Participant 4, Department of Chemistry): «When I am doing science, let's call it pure science, whatever, then I sit there and think always in terms of properties of small parts, try to calculate what is happening, but this isn't about nature as such, it is about the process of science.» (Participant 5, Department of Physics and Technology). Interestingly, in his article, Khushf noted a split between scientists and philosophers of science, with the former presented as having confidence in reductionist approaches to knowledge and the latter presented as believing that full reductionism has never characterized the theory or practice of any science. While the scientists in our exercise demonstrated that scientists can also be sensitive to the limitations of reductionist approaches and express little confidence in its usefulness for particular circumstances and for particular phenomena, their major difference with Khushf was that they maintained a belief in its use as a helpful heuristic.

This led into discussions of methodological versus ontological reductionism,[3] which for participants was a distinction that was not always clear, and particularly not in the article by Khushf: «What is reductionism? It varies. Is it the methodological view or the ontological?» (Participant 7, Department of Physics and Technology); «There are 2 types of reductionism and I am not sure which fits better to his.» (Participant 5, Department of Physics and Technology). Indeed, Khushf (2004) can be seen to be arguing against both a metaphysical form of reductionism as well as the appropriateness of methodological reductionism for nanoS&T. The primary objection the participating scientists raised on this point was that while they might have agreed with Khushf on the metaphysical dimension, they did not feel as though his limited description of the systems theoretic alternative gave them any real methodological guidance: «Systems theory is presented as an alternative but what is systems theory? … it was not defined in the paper.» (Participant 6, Department of Chemistry); «[T]o divide into smaller pieces as a way to understand a whole, is a method of thinking that is so ingrained that to go another way is completely unrealistic.»* (Participant 8, Department of Chemistry). The occupying question for many of the participating scientists was: When is reductionism useful?: «In many cases reductionism is not the best way to do science … you could get a more fundamental description but it doesn't give you any more understanding of what is going on […] You could describe the stockmarket in terms of atoms, an insanely large model of atoms, it would be possible, but is that useful?» (Participant 7, Department of Physics and Technology). Following this line of inquiry, one could also ask what makes fruitful and relevant reductionism? Where and how are the boundaries drawn between methodological and ontological reductionism? What role do social factors play in this boundary work? Unfortunately, the connections, blending, demarcations and negotiations that occur between positions of methodological and ontological reductionism was a rich issue that remained unexplored in Khushf's more simplified presentation of an old versus a new view of science. Our exercise certainly suggests that the boundary work scientists perform between methodological and ontological reductionism in their daily work would be a topic worthy of further research.

The issue of specificity and clarity of concepts was a major point of discussion among all of the groups. The participants felt that Khushf talked in very abstract terms without the level of detail and supporting examples that they as scientists would need for it to be considered a valuable and/or useful «general model of science»: «There are very few examples and very few illustrations to make his point […] The arguments he brings up are not sufficient to support his thesis.» (Participant 4, Department of Chemistry); «He does not show any examples for this conclusion, there could be evidence, but it doesn't show.» (Participant 9, Computational Biology Unit). In addition to having these concerns about the general style of the article, they also felt that Khushf failed to adequately define his key concept of systems theory – specifically what its concrete characteristics are and/or how it might be operationalized in research practice: «I did not really understand his alternative. It is not well illustrated in my opinion.» (Participant 4, Department of Chemistry); «I don't know what he means by systems theory […] He doesn't define it very well.» (Participant 5, Department of Physics and Technology).

Furthermore, the participants wanted more detail on what exactly was meant by the term «convergence». For example, Khushf states: «Within nano-science, physics, chemistry and biology are no longer related in the hierarchical, asymmetrical relation of dependence that characterizes the grand reduction […] Rather, cutting edge work in each discipline leads them to converge, and each informs the other.» (Khushf 2004: 29). A question of discussion on this topic was whether the notion of «converge» here meant something more like «borrow» or «unite». While in isolation the term converge might be understood as something like a process of unification, in the above quote it is not clear that this is what is meant. Each discipline or field of scientific activity «informing» the other does not necessarily mean each merging into the other. That different disciplines draw on insights and methods from others, and then mix and merge to some extent, was highlighted as nothing particularly new to nanoscience, the argument being that new integrative subdisciplines such as biochemistry, quantum chemistry, and computational biology, are emerging all the time: «There is a field of quantum chemistry and physics has always been connected to quantum chemistry. There is an overlap, but that has nothing to do with nano.» (Participant 7, Department of Physics and Technology); «It is definitely overlapping, but not converging.» (Participant 10, Department of Biomedicine); «That is a weak point. You have always had subjects crossing each other, that is nothing new.»* (Participant 8, Department of Chemistry). However, it was also suggested that arguing that physics, chemistry and biology would converge failed to acknowledge the huge amount of diversity existing within these broad and overarching disciplinary terms: «Saying that physics and biology will merge … well what do you mean by that? They are two very large fields!» (Participant 3, Department of Physics and Technology). In this sense, claiming that chemistry, physics and biology are converging could be seen as either a huge claim that fails to acknowledge and account for the diversity within each of these disciplines, or an entirely trivial claim that fails to acknowledge the way in which blended subdisciplines have been consistently emerging through time.

There was also some confusion about what Khushf was referring to in his suggestion that a hierarchical relationship between the sciences no longer applied for nanoscience. There were particularly intense discussions around his statement that: «New 'laws' will emerge for the nano-region.» (Khushf 2004: 29). The first question related to what was actually meant by the phrase «new laws», a matter that was further obscured by the fact that Khushf himself places the word laws in inverted commas: «Does he mean new laws as in Newton's laws, or new phenomena, or new models to explain things?» (Participant 3, Department of Physics and Technology). It was also unclear how the creation of new laws for activities at the nanoscale would necessarily translate into standard hierarchies of explanation not applying. While it might be accepted that different laws may hold true for different scales of investigation, and that new laws may emerge for the nanoscale, as one attends to different scales of investigative interest, a hierarchy of explanation may still be seen to apply. Of course, it may not, but Khushf's argument was seen to require further clarification, more detail, and/or supporting examples to hold any real weight on this point.

Finally, the scientists challenged Khushf's claims about the uniqueness of the nanoscale for advancing a systems theoretic model, which they saw as a rather arbitrary selection: «Nano is not a big revolution … we have been gradually going in this direction for many years.»* (Participant 2, Department of Mathematics): «If there was a break anywhere it was maybe in quantum mechanics.» (Participant 4, Department of Chemistry); «There has been a gradual change over time, from the 1800s … so why should it come now, this revision of the earlier image?»* (Participant 11, Department of Chemistry). As Khushf himself points out, other fields in science, such as the work on chaos and complexity, have challenged the adequacy of reductionist approaches and led to a development of systems-based theories as alternatives. What Khushf claims though, is that these challenges have been taken in isolation, whereas with nanoS&T, different areas of challenge are converging, leading to an overall challenge to the «grand project of reduction» as a whole. The scientists', however, also had criticisms regarding Khushf's other areas of challenge. On the issue of bridging classical and quantum domains, the comment was made that it is not only scale that is important for the influence of quantum effects, other factors are also important, and it may therefore not necessarily only be at the nanoscale where one must bridge quantum and classical worlds: «It is not necessarily true that the nanoscale is the only place where quantum and classical worlds collide.» (Participant 7, Department of Physics and Technology); «If you have few particles or low temperatures you can have quantum effects, even though it is not on the nanoscale. So it is a bit fuzzy what he means by this scale thing.» (Participant 3, Department of Physics and Technology). With regard to the point about blurring lines between pure and applied domains, on the one hand questions were raised concerning whether work on the nanoscale was really unique in this sense: «This blurring always exists, maybe for 100 years. I don't think this is a unique feature.» (Participant 9, Computational Biology Unit). On the other hand, questions were raised about whether this blurring was really as strong as was being claimed. Many of the participating scientists viewed their work as very much falling within a pure or basic research domain and strongly resisted attempts made by the course teachers to blur this boundary (e.g. by asking them to imagine future applications of their work): «It is not so easy for me to think about applications … I have a genuine interest in the system [and] its characteristics.» (Participant 11, Department of Chemistry). In this sense, it might be argued that the blurring that is occurring across these domains could be viewed more as an initiative of science policy and funding regimes than related to anything inherent in the field of nanoS&T itself: «Does the nanoscale blur this boundary or does politics and the way we think in society blur it? Even when you are not at the nanoscale there is a cry – what is it good for, what you are doing? If you want money you have to show that what you are doing is useful for society, but is it nano? It is not necessarily restricted to the nanoscale.» (Participant 6, Department of Chemistry). The group discussions indicated that the nanoscientists in our exercise were not convinced by Khushf's arguments for nanoS&T as something uniquely demanding of a new image of science. What they saw was perhaps nanoS&T being used as a case to advance an already existing ideological commitment to systems-based thinking.

Having conducted this exercise of reflection, we would agree with Khushf (2004: 22) that there are indeed «opportunities for establishing a rich dialogue between the sciences and the humanities», and that looking «at what is actually taking place within the disciplines, [and] at the boundaries between the disciplines» would be a particularly fruitful approach to overcoming «overly general and unhelpful notion[s] of the scientific enterprise». However, we are not convinced that Khushf's paper managed to address these points in a satisfactory manner.

What did Schmidt say?

Jan Schmidt (2004) states in his article that nanotechnology is an umbrella term for a wide range of technologies. Nevertheless, he argues that «the umbrella term also reveals an endeavour of recent engineering sciences and science-based technologies to find a *fundamental technology*, in other words: a root or core technology» (Schmidt 2004: 35). He refers to this endeavor as representing a new kind of reductionism—technological reductionism—that he suggests has yet to be recognized by philosophy of science. In Schmidt's view, technological reductionism is the «metaphysical core of the heterogeneous and diverse fields of the umbrella phrase 'nanotechnology'» (Schmidt 2004: 40) and even though it appears to be heterogeneous, diverse and pluralistic, he claims that the technological reductionism underlying nanoS&T is anti-pluralistic at its core.

Schmidt (2004) relates the technological reductionism endeavor to the search in physics for a grand unified theory, and suggests that similar to the concept of unity in physics, technological reductionism is supposed to be a unity of technologies, so that one «mother technology» enables all other «daughter technologies». In other words, he describes it as: «Technology t_1 is said to be reduced to technology t_2 if, and only if, the advancement of t_2 is fundamental to the advancement of t_1.» (Schmidt 2004: 2).

In making his argument about the technological reductionism underlying and driving forward nanoS&T, Schmidt (2004), like Khushf (2004), also draws heavily on the NSF report edited by Roco and Bainbridge (2002). In Schmidt's view, however, Roco and Bainbridge (2002) take too lightly the idea that the ambitions of convergence and unification are far from novel. Schmidt (2004) suggests that the scientific ambition to link and unify quantum mechanics, solid-state physics, inorganic chemistry and molecular biology are classical efforts of convergence that continue to remain unsolved today:

> The theoretical gaps seem to reflect that nature is ontologically multi-tiered and coarse-grained. But the visionaries of nanotechnology fail to notice the state of the art in physics. They just orient themselves toward the heuristic objective of physics, which is mainly the quest for a fundamental theory of everything. (Schmidt 2004: 38)

According to Schmidt, however, even though there may be no scientific basis to justify the claim of a radically new era, the visions alone are a sufficient indicator for this diagnosis. Quoting Alfred Nordmann (2003), Schmidt (2004) stresses that visions often turn into facts, and open roadmaps to reality. Thus, Schmidt also creates a philosophy of nanoscience that is largely based on visions of the field, and particularly the vision presented by Roco and Bainbridge (2002).

Schmidt (2004: 46) extends the vision of technological reductionism to its extreme – the view that with nanoS&T, «Everything will be shaped, designed and controlled within the limits of the laws of nature.» Schmidt suggests that this is «pure Baconianism» and is concerned that this vision of science-based manipulation of the world apparently leaves no room for critical reflection, although he retains his position that «it remains a question of politics and subpolitics whether we will accept this dissolution of our cultural distinctions.» Schmidt therefore finds it surprising that this almost naive trust and confidence in technological optimism finds a renaissance in nanotechnology, since the negative effects of technology within society have been perceived and reflected upon throughout the 20th century. Accordingly, it is his position that «[f]or the philosophy of science it remains a challenge to critically show that the vision of a totally shaped world overestimates the power of science and the power of men» (Schmidt 2004: 46).

What did the nanoscientists say?

The first question our participating scientists focused on in reflecting on Schmidt's article was: Whose vision is Schmidt describing? As nanoscientists, the participants did not feel that the vision of technological reductionism was their vision and they therefore engaged in extensive discussion about whose vision it actually was: «Who is responsible for all these promises? Is it the science fiction people? Us? Drexler?» (Participant 7, Department of Physics and Technology); «[Schmidt] claims that it is the claim of nanovisionaries, it is his impression. I hadn't seen it [this vision] until I read this […] it might just be the science board in the US.» (Participant 3, Department of Physics and Technology). While Schmidt refers to «visionaries of nanotechnology» in general, and briefly describes the work of Richard Feynman and Eric Drexler, the majority of his arguments are, as stated above, based around the NBIC report by Roco and Bainbridge (2002). As a report emanating from the National Science Foundation of the United States, one could argue that this document is certainly worthy of analysis and commentary. However, the lack of resonance of the described vision with the scientists participating in our exercise led them to question the strength of Schmidt's argument (that a single endeavor of technological reductionism unites the broad range of activities of nanotechnology), based as it was on an analysis of a vision actually expressed by only a handful of people and not necessarily those actively engaged in research in the field. Schmidt appeared to be writing a philosophy of nanotechnology based on nano lobbyists' rhetoric rather than actual research practice, and our participants questioned both the validity of this approach and its relevance for their own work.

Nordmann has suggested that the work of maintaining the unifying power of concepts is

> […] not performed by researchers who formulate new theories, train graduate students, edit disciplinary journals, establish and articulate a paradigm. It is performed for the most part by advocates and activists, visionary policy makers, scientists when they speak to the public or argue for future funding — and by philosophers, ethicists, social scientists. (Nordmann 2007: 223)

This means that one could certainly argue that the visions of a new field of research advanced by major funding agencies and proponents of a technology can have considerable force in shaping research efforts, but our participants questioned who this vision was really for. The vision of finding a root or core technology was not one that they saw guiding their own research projects, and they were certainly skeptical about the extent to which it could be said to guide nanotechnology research as a whole: «I am not sure the nanotechnologist people are sitting there thinking, ahhh, now we really will make the fundamental technology to rule all the other technologies.» (Participant 7, Department of Physics and Technology). Some of the scientists specifically described the technological reductionism vision as an image for the public rather than a driving force for actual science: «This very visionary image of nanotechnology, it is not what it [nanotechnology] is for us, but […] it is society's vision.»* (Participant 2, Department of Mathematics). The participants also argued that this type of vision could have considerable socio-political force, for example in helping to win legitimacy for nanotechnology as a prioritized field investment: «[W]hen science is a major budget host, it [the vision] may be needed for the rest of the society» (Participant 7, Department of Physics and Technology). In this sense, the vision of technological reductionism might be seen not primarily as an endeavor of recent sciences, but as more an endeavor of modern science policy.

The participants in our exercise were very aware of the way in which scientists negotiate their work in relation to policy and particularly funding requirements (a point well empirically demonstrated by Waterton 2005). They repeatedly discussed the idea that the term «nano was commonly invoked simply to attain funding for work that had been ongoing for a number of years under another name: «You just put a new name on it to get it to look fancy.» (Participant 3, Department of Physics and Technology). They also acknowledged on several occasions that if one wants to secure funding (in any field, not just nanoS&T) there is now strong pressure to explain one's research in terms of its potential practical application and benefits: «When we apply for funding, we are actually trying to sell our research, and a [technological] application helps!» (Participant 7, Department of Physics and Technology). They suggested that such forms of pressure could also lead to more dramatic visions being expounded in the public sphere. Ethical questions around this, such as «[Are we] saying that the scientists are playing an unfair game … fooling society???» (Participant 6, Department of Chemistry), were also raised and debated. Through these conversations it became clear that the complex interplay between science and policy in the modern context means that the socio-political dimensions of any visions of science should be acknowledged and accounted for. In this sense, by analyzing the vision of technological reductionism as revealing an endeavor of recent engineering science and technology, our exercise indicated that Schmidt's way of presenting his analysis neglected to specifically refer to the important socio-political dimension of this vision and the complex interplay of science and policy in the modern context.

A related point that our participating scientists commented on was the use of language. Schmidt (2004) refers to nanotechnology as having both «hegemonic» (p.39) and «imperialistic» (p.40) tendencies and the scientists raised the issue of the heavily value laden content of these words. This was seen as strongly negative language and it could perhaps be argued that this type of language highlights the article as an example of nanoS&T being scrutinized by a normative philosophy of science, as argued for by Nordmann (2007). These terms are also both more commonly used in reference to politics than science, which is interesting given the reflections noted above about the socio-political dimension of the vision under analysis. An additional point about language can also be made concerning the quote within which one of these terms occurs. Schmidt (2004: 39) states that: «Nanotechnology, this is my main thesis, aims to be a fundamental technology ('root technology') with hegemonic tendencies: Nanotechnology presents itself as *the* basis for all other technologies.» During our exercise, it was noted, in this case by a member of the teaching team, that nanotechnology cannot present itself as anything, but rather it is people who present it as something and people who have aims for it. The discussion was then again focused on which people have the visions and the aims for nanotechnology that Schmidt analyses? By his form of expression, Schmidt masks this feature of agency, and therefore the scientists continued to ask who exactly it was that was presenting nanotechnology in this way. An additional problematic issue was raised in relation to the generalization that the objective of physics is «mainly the quest for a fundamental theory of everything» (Schmidt 2004: 38). While this may be an objective for some, it was questioned whether this was really the aim of most physicists today: «It is a mistake to hang this on all physicists.»* (Participant 2, Department of Mathematics).

What these reflections on Schmidt's article reveal is a range of questions about the relationship between visions of emerging technologies, such as nanotechnology, and the daily practice of scientific researchers working in the field. In touching on important questions about the relationship between science, society and policy, these reflections also raise questions about the methodological approaches of work in the philosophy of science, including questions such as: To what extent should philosophy of science be based on visions of the field as opposed to daily research practice? How are these different aspects integrated in reality and how might they be integrated in philosophical research? How can the socio-political dimensions of both the visions and the practices be incorporated into philosophical descriptions? Furthermore, what does it mean when scientists are highlighting the way philosophers are neglecting to clearly articulate socio-political dimensions of science?

General lessons

One of the issues that cut across all three of our discussion groups was that of the writing style of the two philosophers. In addition to expected problems with unfamiliar terminology—«I read Wikipedia for maybe two nights to digest these terms!» (Participant 9, Computational Biology Unit)—the scientists felt there was a general lack of specificity and use of illustrative examples. This style of writing also led the scientists to be critical of the strength of the philosophical arguments, not because they found them to be illogical but because for them the strength of an argument was enhanced by specificity and supporting evidence or examples. This difference in styles of argumentation also made the scientists rather critical of the methods used by the philosophers to develop their descriptions of science. As the descriptions that both of the philosophers gave of nanoS&T did not have a large degree of resonance with the scientists' own experience and practice, in order to be convincing the arguments were seen to need support from multiple concrete examples. Basing a philosophy of science on generalizations and a limited number of visionary documents did not hold a lot of weight for our scientists and they may therefore argue, in common with Mayr (2004), that an empirical approach to philosophy of science may be a more appropriate research method. These reflective sessions therefore highlighted how different styles of communication and argumentation can inhibit effective and fruitful communication across disciplines of social and natural science.

One of the claims made by Khushf (2004: 24) was that «Scientists generally do not spend much time reflecting on the nature of the scientific enterprise» On this point, our scientists agreed, that reflecting on the nature of science was not something they generally spent much time on: «We ask questions about how things work, not how we find out about how things work.»* (Participant 2, Department of Mathematics). When asked why this was the case, it was suggested that they generally did not take the time, or had not been «trained» to do so: «For me, the most important thing is to get results and I don't think so much about other things, like those here.»* (Participant 1, Department of Biomedicine); «We have not been trained to do this […] it was not indoctrinated into our thoughts at any time, this method of reflecting on things.»* (Participant 8, Department of Chemistry). Interestingly, this creation of space and training for broader reflection was the general aim of our course. The positive evaluations it received indicate that after some «training», or more accurately, encouragement, to engage in reflections on the nature of science, many found this an interesting and relevant exercise: «I feel that this course has been an «eye-opener». I didn't think much about my responsibilities as a scientist except my responsibility to deliver results. Now I see that there is much more to science and being a scientist than that.» (Anonymous review form). What the session reflecting on the two specific philosophy of science articles also did, however, was raise the question about how much time philosophers of science spend reflecting on the nature of *their* enterprise: what are appropriate methods for their type of research, how should their research be communicated, who is the audience, and what is the relevance, visibility and accessibility of the research for scientific practitioners? While we believe that having scientists read and reflect on philosophy of science texts had value for the scientists, we also believe it can have value for philosophers, as a way to stimulate their own reflexivity about the nature of their field and deepen the content of their analyses.

The value of iterative interaction across social and natural sciences is multifaceted. In relation to the exercise described in this paper, we can see that having scientists read and discuss philosophy of science written about their field can create a space for reflection that is otherwise not necessarily available in the busy life of daily research practice. Reflection on general images of their field can thus force scientists to confront questions about their work, methodology, underlying assumptions, and outside opinions and views, and also the implicit values, goals and directions of their research field. What our exercise also revealed, however, was that such exercises can potentially have equal value for philosophers, not only because they allow them to test the resonance and robustness of their concepts, but also because they raise more general questions for their own reflection, such as who is the philosophical work for, what is it based upon, what does it aim to achieve, and what styles of communication are required to reach different audiences? Perhaps most interesting for us was the way in which the direct interdisciplinary interaction enabled the questions of interest to be reframed. While we had originally wanted to investigate the scientific literacy of the philosophy of science articles, through the exercise, the key issue of interest became not who was right and wrong, but rather how we might all better communicate and engage in a co-production of knowledge. Perhaps it is this emergent property of the interaction that should be viewed as the most valuable.

Conclusions

In this paper we have presented some themes of discussion stemming from an interdisciplinary exercise involving nanoscientists and philosophers of nanoS&T. In this exercise, early career scientists were asked to read and discuss papers in philosophy of science that focus on nanoscale science and technology. While the scientists discussed the accuracy of some of the claims made by the philosophers, the majority of the discussions centered more on the methods of philosophy of science and on the style of communication and argumentation. This exercise revealed the barriers that continue to inhibit communication between philosophers of science and scientists. Interestingly, the problem of communication was also raised in the discussed paper by Khushf (2004), where it was traced back to the two groups holding different views on science (holism versus reductionism). In our empirical experiment, however, the communication barrier seemed to stem more from different styles of argumentation and standards of proof across the groups, with the scientists wanting more precision in language and support from specific examples. In this respect, our experience provides insights for philosophers of science into how their work is read by scientists and what might be required for them to extend the audience for their work into the scientific community directly.

If the current approach of desiring scientists to engage with social and ethical questions continues, new methods and approaches for generating such engagement will increasingly be required. The approach presented in this paper, of facilitated interdisciplinary discussion around articles of relevant philosophy of science, is one promising method for having scientists reflect on more general questions relating to their field. It is, however, also a method in which philosophers stand to gain. While the philosophers who benefited in this exercise were not the authors of the texts directly, but rather members of the teaching team and the two students of the discipline present, one might imagine a situation in which this was not only the case. This type of exercise could be oriented around texts in development rather than those already published and thereby involve direct interaction between authors writing philosophy of science and scientists active in the field. This idea was highlighted as particularly relevant by one of the anonymous reviewers of this paper, who saw the exercise as highlighting both the existence of «poor pieces of philosophy» in peer-reviewed publications and the ability of scientists to be «good readers who are able to uncover weaknesses».

Interdisciplinary dialogue and iterative reflection could help scientists and philosophers of science not only understand each other, but also create potential for each to benefit from what the other has to offer in both expected and unexpected ways. Nordmann (2007) has presented «nanotechnology» as an entangled concept, including ideas, visions and work from multiple actors and disciplines. In our opinion, there is therefore enormous potential for interdisciplinary dialogue, mutual learning and a co-production of knowledge across the social and natural sciences within ELSA studies of nanoS&T, and both sides just need to embrace the opportunity.

Notes

1 Also referred to, particularly in the United States, as ELSI – ethical, legal and social implications.

2 It also meant that the three participants in the exercise who were invited to be coauthors of this paper also represented three different disciplines.

3 The difference between methodological and ontological reductionism has been well articulated by Longino (1990): «Reductionism is both a methodological practice and a metaphysical view. Methodologically, reductionism is the practice of characterizing a system or process in terms of its smallest functional units. Metaphysical or ontological reductionism argues that those smallest functional units are what is real and that all causal processes can ultimately be understood as a function of interactions among these least bits. Methodological reductionism is often very useful in guiding researchers to the mechanisms or material constituents of a process […] Metaphysical reductionism, however, conflates the pragmatic successes of local applications of methodological reductionism with both a guarantor of truth and the promise of universal reducibility.»

* One of the discussion groups was held in Norwegian. The quotations here are author translations.

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