NOTES AND RECORDS

*Notes Rec.* (2019) **73**, 353–367
doi:10.1098/rsnr.2018.0054
*Published online* 28 November 2018

# 2017 WILKINS–BERNAL–MEDAWAR LECTURE: WHY PHILOSOPHY OF SCIENCE MATTERS TO SCIENCE

by

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In an era where science is increasingly specialized, what is the value of interdisciplinary research? I argue that research across disciplinary boundaries plays a pivotal role in scientific inquiry, and it has a threefold value: it is *exploratory*; it is *unifying*; and it offers *critical engagement*. Philosophy of science is an interesting example of interdisciplinary research at the junction between the sciences and the humanities. What good can philosophy of science do for science? Despite anecdotal reports to the contrary, philosophy of science can in fact do important work for science. When it comes to critical engagement, I highlight what I call the *social function of philosophy of science* and I illustrate it with three examples taken from contemporary debates about evidence, progress and truth in science. A socially responsible philosophy of science—which is not afraid to speak up for evidence, progress and truth in science—best serves the needs of science in a tolerant, pluralist and democratic society.

**Keywords: philosophy of science; interdisciplinarity; evidence; truth; progress; Newton; Kant**

## A CELEBRATION OF PHILOSOPHY OF SCIENCE

In an era where science is increasingly specialized, what is the value of interdisciplinary research? In this lecture, I will make the case for research that crosses disciplinary boundaries by attending to three main tasks. First, I want to celebrate what in my view is the threefold value of interdisciplinary research. Second, I highlight the particular role of philosophy of science (my research area) within the broader field of interdisciplinary research. Third, I make the case for what I call the *social function of philosophy of science* and show how and why this particular kind of interdisciplinary research best serves the needs of democratic societies.

But, if I may, I would like to start with a brief intellectual and biographical note. The notification letter for the Wilkins–Bernal–Medawar award mentioned my 'interdisciplinary interest in and communication of modern philosophy and science: particularly in relation to physics, and the thinking of Newton, Kant and Pauli'. When I received the letter, I

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remember smiling at the thought of the Newton, Kant and Pauli trio—what a most unusual combination of research interests I have always had, and what would be the chances that one day I would get to stand at the Royal Society to receive an award for having such an idiosyncratic combination of interests. What is the underlying thread that binds these seemingly very diverse research interests and for which I am receiving an award tonight?

The answer is interdisciplinarity. Think of each and every one of these three scholars. Isaac Newton, President of the Royal Society (1703–1727), wrote the *Philosophiæ Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*, as physics was called at the time), where he laid out the fundamental laws governing classical mechanics (from planetary orbits to free fall and tides, among many other phenomena). But he also enjoyed speculating about chemistry and chemical experiments. Indeed, the very same Newton who famously declared 'I feign no hypotheses' in the General Scholium of the *Principia*, indulged in experimental speculations about the role of the ether in the 'Queries' added to the *Opticks* giving rise to a very influential tradition of speculative Newtonian experimentalism.[1] This tradition thrived in Britain and in the Netherlands throughout the eighteenth century with Herman Boerhaave and Stephen Hales,[2] and ultimately influenced Immanuel Kant's theory of matter.[3] But Newton was not just interested in physics and chemistry. He actively engaged with metaphysics and theology. In *De gravitatione* (an unpublished manuscript written most probably before the 1678 *Principia*[4]) Newton defended the thesis that space is an affection of being—be it God, human minds or material bodies. And since God exists always and everywhere, space and time—Newton argued—must exist always and everywhere. Indeed, in the General Scholium to the *Principia* Newton grounded absolute space and absolute time on what he called the 'Lord God Pantokrator' ruling 'all things, not as the world soul but as the lord of all'.[5] It is this overarching philosophical–metaphysical framework that ultimately explains Newton's views about the nature of gravity, mass, space and time.

This Newtonian tradition proved hugely influential for the philosopher Immanuel Kant. Best known among philosophers for his groundbreaking contribution to theoretical philosophy, moral philosophy and aesthetics, Kant was also a keen scholar in the natural sciences. He wrote essays about the age of the Earth (1754), the causes of earthquakes (1756), the theory of winds (1756) and the volcanoes on the Moon (1785), among others.[6] His very first text, back in the late 1740s, was entitled *Thoughts on the True Estimation of Living Forces* (1746–1749).[7] The topic was the then lively debate between Cartesians and Leibnizians on the nature of forces at work in elastic collisions (what at the time was called *vis viva*, the ancestor of our modern notion of kinetic energy). Inspired by Newton's *Opticks* and Hales's *Vegetable Staticks*, the young Kant referred to gravity and repulsive force (or elasticity) as two grounds for a plurality of effects in nature. Many years later, in the *Metaphysical Foundations of Natural Science*,[8] Kant took attraction and repulsion as two fundamental forces through which he articulated a sophisticated view of the lawful unity of nature and the necessity of the laws of nature.[9] He saw his project as continuous with the scientific work of Newton in providing metaphysical foundations for the physical sciences.

The same continuity between philosophy and science is evident among the founding fathers of quantum mechanics. This is where I started my philosophical journey as an undergraduate student at the University of Rome *La Sapienza*. I read the Bohr–Einstein debate on the completeness of quantum mechanics in 1927–1935 and, as I began my postgraduate studies in London, examined the role of Wolfgang Pauli within the so-called

Copenhagen interpretation of quantum mechanics. Bohr read the Danish philosopher Kierkegaard as much as Einstein read Ernst Mach.[10] The debate on the nature of physical reality between Einstein–Podolsky–Rosen and Bohr[11] in 1935 is a profound philosophical debate as much as it is a debate about the epistemic limits of quantum mechanics. Wolfgang Pauli's conversations with Bohr and Heisenberg in the early 1920s on the nature of quantum phenomena and the Pauli exclusion principle became the topic of my doctoral work, and the basis of my first monograph.[12]

It is this dialogue between philosophy and science—well exemplified by the works of Newton, Kant and Pauli, among many others—that has always fascinated me. And it is this dialogue between philosophy and science that I want to celebrate in this lecture. In an era of increasing specializations, what is the value of crossing disciplinary boundaries? Both philosophers and scientists these days do not necessarily read other subjects at university; nor might they be trained in a broad range of topics in senior schools. Large scientific collaborations enforce a granular level of scientific expertise. In philosophy too, there is a tendency to become specialized at a very early stage in the postgraduate education. The whole 'ethos' of modern research both in philosophy and in science—reflected in institutional practices of how scientific research is incentivized; how research outputs are evaluated; and research funding distributed—has been transformed from the times of Newton, Kant and Pauli. What good, then, is interdisciplinary research today? Answering this question is my first task, to which I now turn.

## The threefold value of interdisciplinary research

Let me start by recounting some contemporary facts that illustrate why we need interdisciplinary research. It is a fact that some of the global challenges that confront our society today require an interdisciplinary approach. From climate change to population health, from fighting famine to tackling violence in our streets, interdisciplinary approaches are often required.

Consider, as an example, aggressive behaviour behind knife crime that has sadly become a daily reality in our streets. What causes aggressive behaviour? What could be done to prevent it? Obviously, there are no easy answers to these questions, and this is a situation where an integrated interdisciplinary approach might work best. For example, in her book *Studying Human Behaviour: How Scientists Investigate Aggression and Sexuality*, the philosopher of science Helen Longino charts the course for a pluralist interdisciplinary approach to understand aggressive behaviour.[13] She argues that to explain successfully aspects of human behaviour—such as aggression—it is necessary to abandon the presumption that there is one single correct approach and acknowledge the advantages of adopting a form of theoretical pluralism. In the example in question, Longino argues that considering behavioural genetics, a social–environmental approach, neurobiology and developmental systems are all important in an explanation of aggressive behaviour. Although each approach is characterized by distinctive questions, methods and assumptions, and although each differs in identifying the causes of the aggressive behaviour, at the same time all approaches are needed because they reinforce each other and help tease out different causal factors at play.

The same is true about tackling some challenges in developing countries where, in addition to agricultural technology and the so-called 'miracle seeds', more recently artificial intelligence (AI) and robotics have been brought in to solve very specific problems. Recent news headlines have highlighted, for example, how robotics can help improve the living standards in rural communities (for example, by having robots carrying out daily tasks such as carrying water from a distant well). Resorting to AI to tackle societal challenges in turn raises important ethical questions about the responsible use and monitoring of technology. What is the just distribution of technology in developing countries? Who is benefiting from it? How do women's roles in rural communities change as a result of introducing technologies? Is this use of technology liberating? Or is it fostering further inequalities? Philosophers of AI have recently begun to address some of these issues and explore the ethical implications of increasingly resorting to AI and robotics.[14]

Or consider, as a further example, how interdisciplinary research has revolutionized medical diagnostics. The first PET scan, routinely used these days in cancer diagnostics, was carried out at CERN in Geneva, using technology originally developed for particle physics. In 1968 Georges Charpak introduced multi-wire chambers that revolutionized the old-fashioned method of inspecting photographs of bubble chambers. Professor David Townsend in the Department of Medicine at the University of Tennessee Medical Centre began to work with Charpak multi-wire chambers at CERN in 1970, pioneering the new technology of PET scans and combining it with computed tomography. The first PET scan of a mouse took place at CERN in 1977, and the radiobiology group at CERN played an important role in studying the practical uses and damaging effects of ionizing radiation on living organisms.[15] This fruitful way of exporting tools from physics to medicine is a powerful reminder of the value of analogical reasoning in modelling across different areas, a topic to which the philosopher of science Mary Hesse extensively contributed.[16]

These three are examples of what I call the *exploratory value* of interdisciplinary research. One of the main (and surely most familiar) values of interdisciplinary research is to cross disciplinary bridges and transfer knowledge from one field into another one, or to integrate diverse disciplinary fields so as to gain a better understanding of complex phenomena: e.g. how to apply knowledge from particle physics to medical imaging, from robotics to specific problem-solving related to societal challenges; or how to integrate different kinds of knowledge to produce new knowledge (say, about aggressive behaviour). This is an exercise rife with practical and intellectual rewards and with a huge impact on human lives and society.

But there are other reasons why interdisciplinary research is necessary, reasons that have less to do with the needs to address societal challenges and more to do with the working patterns and deliverable outputs in specific fields that increasingly seem to demand a level of interdisciplinary expertise. Consider, for example, cosmology. In contemporary observational cosmology, the use of Bayesian statistics is widespread. The Bayes factor, which measures the ratio between the probability of the evidence D in favour of a null hypothesis $H_0$ (for example, the $\Lambda$CDM model[17]) over the probability of the evidence in favour of a rival hypothesis $H_1$ (say, a variant of the $\Lambda$CDM model), is widely used in both model selection and parameter estimation in cosmology. And yet, Bayesian statistics is not necessarily an integral part of the education and training that students and early career scholars receive in cosmology. In this case, the importance of interdisciplinary education resides in the ability of specific communities to acquire a range of tools and resources that prove indispensable for the delivery of intended research outcomes. Having a well-rounded university education best equips students and researchers to understand the problems at hand, to anticipate solutions and to identify possible common patterns. To return to my example, acquaintance with statistics and the role of the Bayes factor in model selection across a range of diverse fields (say ecology, cosmology or forensic science, for example), is important for understanding the context-sensitivity of the standards of evidence offered by the Bayes factor interpreted along the Jeffreys scale in different fields.

To clarify this point, in observational cosmology it is common to interpret the Bayes factor along a Jeffreys scale that goes from 1 to 10, where the evidence in favour of a null hypothesis $H_0$ over a rival $H_1$ is regarded as either substantial, strong or decisive depending on where the Bayes factor sits on the scale.[18] By contrast, in forensic science, for example, the Jeffreys scale is typically expanded to much higher values. This is because using the Bayes factor to establish whether the evidence favours the hypothesis 'innocent' over the hypothesis 'guilty' in any criminal case requires a more nuanced approach (taking into account a number of important circumstantial factors) and a more fine-grained Jeffreys scale. This is an area where philosophy of science provides a helpful guide in assessing the prospects and problems of interpreting statistical evidence in science.[19]

I call this the *unifying value* of interdisciplinary research. Interdisciplinary research matters because it allows us to identify possible inferential strategies, methodological approaches and patterns common to very diverse research fields, as well as to investigate the epistemic limits and fruitfulness of these universal features in any specific field of inquiry.

But there is a third reason why interdisciplinary research matters. Sometimes interdisciplinary research is not just functional to finding common inferential strategies or patterns. Nor is it limited to explorations of how we transfer tools successfully from one domain into another. Often enough the goal of interdisciplinary research is to engage critically with a discipline. I call this the *critical engagement* value of interdisciplinary research. I have already mentioned the role that philosophy of science can play for both the exploratory value (think of Longino on aggressive behaviour, or the ethics of AI or Hesse's work on analogies) and the unifying value (with philosophy of probability, be it Bayesian inferences or frequentist methods). But it is really primarily to this third critical engagement value that philosophers of science have contributed and can contribute most. And in what follows, I unpack and focus upon what is involved and what is at stake in the critical engagement value of interdisciplinary research when it comes to philosophy of science.

## The role of philosophy of science within interdisciplinary research

What good is philosophy for science? Or better, as the title of this lecture suggests, why does philosophy of science matter to science? That philosophy of science matters to science is not a foregone conclusion. On the contrary, philosophers of science have been the target of bad press among scientists. Philosophy of science has often been perceived as a useless intellectual exercise. At other times, philosophy of science has been declared incapable of making progress and keeping up with science and scientific advancements. But to me, as a budding 18-year-old student who wanted to read philosophy at university, the most haunting allegory of how useless a degree in philosophy might be remains the caricature of philosophers given by the ancient Greek playwright Aristophanes in a play called *The Clouds*. Aristophanes described Socrates as the Head of the Thinkery, whose important recent discoveries include measuring the jump of a flea on the floor! Hence, we have a dilemma for philosophers at large and philosophers of science in particular: at best they are useless to science and to scientists; at worst, they are laughable in their pointless endeavours.

What kind of interdisciplinary contribution can philosophy of science ever give? And why does it matter to science? Before I go on to substantiate a positive answer to this question, let me be clear—jokes and anecdotes aside—about what is misguided about this way of thinking about philosophy of science. Dismissive claims about philosophy of science all seem to start from a widespread (and ultimately misguided) assumption: namely, that philosophy *has to be of use* for scientists, otherwise it is of no use.

In response, let me make some gently polemical remarks. Philosophy of science—like any other discipline in the humanities—does not *have to be of use* to scientists (or anyone else for that matter), for it to be of *some use*. We would not assess the value of Celtic archaeology in terms of its use to the Celts. Nor would we assess the intellectual value of Roman history in terms of how useful it might be to the Romans themselves. For we all (I hope) recognize and acknowledge that the intellectual values of archaeology, history, anthropology, etc. should not be measured and assessed in terms of *how useful* these humanistic disciplines are for their subjects of study (past or present). Why should philosophy of science be any different from archaeology, history or anthropology?

I see philosophy of science as a valuable discipline—like any other in the humanities—whose beneficiaries are humankind, broadly speaking. We build narratives about science. We scrutinize scientific methodologies and modelling practices. We engage with the theoretical foundations of science and its conceptual nuances, because science (and scientific knowledge) is a human activity (like many others) that is worth investigating and exploring. And we owe this intellectual investigation to humankind. It is part of our cultural heritage and scientific history. It is part of who we are as a community of epistemic agents that have evolved across time and developed sophisticated scientific practices and a distinctive kind of *scientific knowledge*. The philosopher of science who explores Bayesian methods in cosmology, or who scrutinizes assumptions behind population genetics, *inter alia*, is no different from the archaeologist, the historian or the anthropologist in producing *knowledge that is useful for humankind*. Humanity's rich and evolving cultural and scientific history ought to be studied, and there is always more to discover because our philosophical tools also evolve and are refined along the journey. This leads me to my third and more substantive task for this lecture, namely to make the case for what I call the social function of philosophy of science and how this particular kind of interdisciplinary research best serves the needs of democratic societies.

## The social function of philosophy of science

I shall concentrate on three topics in contemporary public discourse on science and highlight how philosophy of science contributes to these ongoing debates in the public sphere. But before I do so, I would like to focus upon some important and still timely remarks by John Desmond Bernal, one of the three scientists after whom this Medal lecture is named. In the 1939 book *The Social Function of Science,* Bernal gave the following vivid portrait of what he perceived as the tangible risk for science to remain isolated and detached from society:

> There is no getting away from it: to a large extent science has become detached from popular consciousness and the result is very bad for both. It is bad for people at large partly because living in an increasingly man-made world they are gradually falling behind in their awareness of the mechanisms that control their lives.... The far more dangerous grip

> which demagogic fascist ideas can exercise is a measure both of popular ignorance and the need to have something to believe . . .. But it is also very bad for science . . . unless people at large—and this will include wealthy benefactors and Government officials—know what the scientists are about, they can hardly be expected to provide that assistance which the scientist feels his work demands in return for its probable benefit to humanity . . .. Among people of literary culture there is almost an affectation of knowing nothing about science; nor have the scientists themselves escaped from it. In their case it refers to all other sciences than their own. It is one of the rarest things to find good general conversations on scientific topics, and this is true even when scientists are the majority of the company. This was certainly not the case when Voltaire and Madame Du Châtelet conducted philosophical experiments at their house parties or when Shelley discussed chemistry and moral perfection with equal enthusiasm.[20]

Bernal's remarks are a powerful reminder about the importance of public understanding of science, both for science and for democratic societies. They are an invitation to see science not as an isolated specialist exercise (he referred to it as the 'evils of specialization') but as part of our broader cultural history. And he made a persuasive plea for making the public at large feel part of that cultural history that is our common heritage. Unsurprisingly, I think, Bernal in this passage refers to the philosophers Voltaire and Gabrielle Émilie du Châtelet as examples of how science used to be part of the broader cultural tradition and how conversations on science used to take place in philosophical and literary salons in the eighteenth century.[21]

Taking the cue from Bernal, it is to this social function (not just of science but also of philosophy of science) that I want to turn next, because I believe that philosophers and scientists bear similar responsibilities in delivering on such a social function. I further believe they can only deliver on this social function by working together. We owe this joint scholarly effort to our democratic societies, even if the immediate usefulness of this kind of interdisciplinary endeavour might not be self-evident. And to illustrate what I mean by social function of philosophy of science (or how philosophers of science can contribute to public discourse on science), consider these three key words that are so ingrained in our public discourse and yet so elusive, possibly misused in many quarters: 'evidence', 'progress' and 'truth'.

## *Evidence*

Public discourse (and media coverage) about the role of evidence in science is often intertwined with public controversies, agitated by political lobbies and agendas. Consider, for example, debates about evidence for climate change, or evidence for the benefits of children's immunizations, or evidence for economic growth. Of course, it is the job of scientists to find out the evidence (the scientific facts) in each of these cases. But I believe that it is equally the job of philosophers of science to work alongside scientists and explore how evidence enters into forecasts and computer simulations; to analyse how evidence gets calibrated and used to draw conclusions about the likely increase in temperature over the next 25 years, how evidence is used to make forecasts about economic growth or, ultimately, how evidence enters into deciding why it is indeed a good policy to immunize children. It is part of the social function of philosophy of science to work alongside the relevant sciences and build narratives about evidence and its use to inform political decision-making and public policy.

In my own work, I have not been dealing with climate science or medicine or economics, but nonetheless the problem of evidence has been and is a recurrent one for modern physics too. Evidence in some areas of physics does not come forward very easily. It is difficult to harvest, and even more difficult to analyse. Let me briefly return to cosmology as an example and current research on dark matter, which is another area I have been working on more recently. According to the current cosmological model (the ΛCDM model), the universe consists of 70% dark energy, 25% dark matter and 5% ordinary matter. Clarifying the nature of dark matter and dark energy remains an open and pressing question for contemporary research in both particle physics and cosmology. What is dark matter, for example? So far there is a plurality of hypotheses about what dark matter might be; but direct detection experiments have given null results as of today. So where does the evidence for dark matter come from?

Some of the main evidence (but not the only source) for dark matter comes in the form of flat rotation curves of galaxies and dark matter computer simulations for the large-scale structure of the universe. Dark matter is introduced to explain the well-known observation dating back to Vera Rubin and her collaborators' work in the 1970s that the rotational velocity of spiral galaxies instead of decreasing with distance from the centre of the galaxy—as one would expect—is observed to remain flat.[22] This is taken as evidence for the existence of dark matter haloes surrounding galaxies, and inside which galaxies would have formed (the same massive haloes, which incidentally, are necessary to guarantee dynamical stability to galactic discs).

But there are other pieces of evidence that some critics in cosmology have argued invite a more cautious approach to dark matter. More recently, the debate has focused on some astrophysical evidence which takes the name of the Baryonic Tully–Fisher (BTF) relation.[23] This is an empirical relation between the baryonic mass of galaxies vis-à-vis their flat velocities to the power of 4. BTF can be appealed to as evidence that can be explained without the need to introduce dark matter because it can be derived within what is known as Modified Newtonian Dynamics (MOND) by modifying Newton's laws at cosmic scales.[24] However, this same BTF evidence can also be retrieved within the ΛCDM model (i.e. without modifying Newton's laws at cosmic scales) by using sophisticated computer simulations.[25]

How can philosophers contribute to this debate? Clearly, it is not a philosopher's job to give verdicts about who is right or who is wrong in this debate internal to cosmology; and it is certainly not our job to pontificate on the nature of evidence as such. But it is our job as philosophers to reflect on the *explanatory power*, on the *consistency* across scales and on the *predictive novelty* of different theoretical proposals in cosmology vis-à-vis these different pieces of evidence across different scales. Does ΛCDM have the power to explain BTF as opposed to retrieve data? Do dark-matter-free rivals have the same ability of ΛCDM to model structure formation across scales? Do hybrid proposals that have recently been put forward to achieve the best of both worlds in this debate have genuine predictive novelty?[26] These are questions for philosophers of science to ask, to investigate and to try to answer in dialogue with scientists involved in this debate.[27]

Genuinely new knowledge is produced through this interdisciplinary exercise of critical engagement between philosophy and science. Philosophers have a role to play: their work can advance an existing debate, which may be based on questionable assumptions or on different epistemic priorities. Philosophers can contribute to ongoing discussions by elucidating how and why, for example, the disagreement among experts is not so much about the data but more about whether the data provide evidence for a new physics or can instead be accommodated within the existing paradigm, as with this example from contemporary cosmology. Investigating the nature of scientific confirmation, procedures for checking datasets' consistency, inferences used in parameter calibration, methods adopted for model selection or the reliability of computer simulations to retrieve particular phenomena all fall within the remit of philosophers of science—and they are (or should be) an integral part of what a well-rounded scientific inquiry ought to look like. Philosophers can shed light on scientific debates, not because philosophers know better or because philosophers have any normative authority in telling scientists what to do next, but simply because discussions about modelling practices, the epistemic limits of computer simulations, calibration and data-to-phenomena inferences are not the sort of discussions that working scientists typically engage with in their daily job. And, the answer to some of these pressing questions as to whether the data are indeed *evidence for something* depends also on how we—as a community of inquirers—tackle and answer these broader methodological and conceptual questions.

I call this *the enabling role* of philosophy of science in its social function. Philosophy of science enables scientific inquiry by unpacking some of the machinery behind evidence, modelling, calibration, confirmation, explanation, simulation, predictive novelty and so on. In this sense philosophy of science is continuous with the sciences. Our enabling role is to contribute to interdisciplinary discussions with the conceptual tools and methodological sensitivity that we have, as well as to help scientists obtain in the public sphere and to the public eye what Bernal aptly described as 'that assistance which the scientist feels his work demands in return for its probable benefit to humanity'.

## *Progress*

We worry all the time about progress in science. Has science made enough progress? How are we going to measure whether scientific progress has been made in particular areas and on particular targets? Metric-obsessed institutional practices force us to quantify all the time our research impact, and to measure whether milestones towards goals have been met. Questions about progress are entangled with questions about research funding. Should taxpayers' money be spent on research programmes that have not made enough progress on target objectives? But what is progress in science? And how can philosophers help with this question?

Scientists are likely to answer this question in terms of technological advances—look how far we have come! We build satellites and put them into orbit. We will have self-driving cars in the near future. We create new medicines that can fight diseases. Our progress is often couched in terms of discovery: we discovered the Higgs boson; we discovered the mechanism behind DNA replication; and so on. It seems that progress must be measured either in terms of discovery or in terms of technological advances.

Accordingly, a sense of frustration accompanies scientific research programmes where the public perception is that time and money have been invested for apparently no use and no returns—nothing has been discovered yet there, and no immediate technological advances are in sight either, so why keep on investing precious taxpayers' money in something that does not seem to be of any use? Think, as an example, of the current situation in high-energy physics, where, despite scientists' widespread belief that the current Standard Model cannot be the full story (because of a series of theoretical problems still open), nevertheless no new particle obeying a physics Beyond the Standard Model (BSM) has been found as of today. Should we keep investing money to build larger and more sensitive colliders that might be able to detect BSM particles? I have seen countless occasions where, in public talks or events, the public challenges particle physicists on this score. Why spend more money on fundamental research? What use is it for us?

This is another area where I think that philosophers as public intellectuals can and should intervene in public discourse and try to rectify some widespread misconceptions to the effect that either scientific research is of use to someone or it has no use at all (and therefore should not be funded). This short-sighted approach as to how to measure success and progress in science (and relatedly how to communicate it to the public) is based on a philosophical misconception, namely that progress is measured primarily, or mainly, in terms of utility. Philosophy of science teaches us how to think about scientific progress, not just in terms of sheer utility, nor, necessarily, in terms of convergence to a theory of everything that many still dream of (and which, for all we know as of today, may or may not be found). So how to think about scientific progress?

High-energy physics beautifully exemplifies a different way of thinking about progress, where progress is measured by ruling out live possibilities, by excluding with high confidence level (95%) certain *physically conceivable* scenarios and mapping in this way the space of what might be *objectively possible* in nature. I have investigated some of the modelling practices involved in this exercise by looking at, among others, the ATLAS and CMS experiments at CERN,[28] and some of the work done there by the SuperSymmetry (SUSY) group to identify exclusion regions where no signal has been found for these conceivable physical states.[29] This is how physics progresses 99.9% of the time, and in the remaining time someone gets a Nobel Prize for discovering a new particle. But it is not the remaining 0.1% of time that alone defines whether enough progress has been made in particle physics and justifies whether more public spending should go into more sophisticated particle colliders. Equally importantly, progress should be assessed on the basis of the 99.9% of the time that physicists spent ruling out live possibilities and carving out the space of what might be objectively real. This is progress enough in science, and being able to convey it to the public (and government officials) is also the task of philosophers of science. This is an example of what I call the *self-reflective role* of philosophy of science in its social function. Here philosophy of science is not just continuous with the science but provides instead a much-needed meta-level for stepping back, reflecting and evaluating directions of research for assessing progress and success in science.

## *Truth*

Probably the image I have given so far of the philosopher of science engaged in public discourse on science on issues as wide-ranging as the role of evidence and the nature of scientific progress is less well known to many than the more familiar picture of the philosopher philosophizing on truth with a capital 'T'. Philosophers love (or hate, depending on who you ask) discussions about truth in science. An entire debate on realism and antirealism in philosophy of science has raged for more than half a century, and it is still ongoing.[30] This is another area I am currently working on for my ERC-funded project, which aims to defend a realist view about science and argue that it is perfectly compatible with our knowledge being situated or perspectival, namely with our knowledge being from a specific vantage point (that of the theories, models, experiments, instruments and also values we share as a community of epistemic agents).[31] Thus, let me conclude with some very brief remarks about truth and pluralism in science.

Truth is an inconvenient word to be used in both science and philosophy. It carries all sorts of implicit connotations and often stereotypical associations. ‘To tell the truth, and nothing but the truth’ might still be an important norm in legal systems. The idea, however, that there might be a truth about nature immediately ruffles some feathers among philosophers and historians of science, as if there was one single true objective story to be told about nature and as if the aim of science were to get there eventually (by trial and error, but still heading towards truth).

But has not the history of science taught us some lesson there, my historian colleagues would hasten to correct me? Did not we believe in ether, in the geocentric system, in all sorts of elastic fluids (still evident in Dalton’s atoms), which we now consider mistakes of a bygone past? How can we be sure that the same fate will not fall upon our Standard Model in high-energy physics 200 years down the line? Is not science subject to scientific revolutions and dramatic conceptual changes as Thomas Kuhn emphasized in the 1960s?[32] And are not even our best scientific models just idealizations, ‘felicitous falsehoods’ which provide understanding but not truth as some philosophers of science have also recently argued for?[33] And anyway, what is this phantom called ‘Truth’ that philosophers of science who call themselves ‘realists’ have put on a pedestal as the goal or intended aim of scientific inquiry, if not what a particular community of inquirers is warranted to believe at a certain point in time (as the philosopher Hilary Putnam argued for, building on the American Pragmatist tradition[34])?

It gets worse. Is not truth in science associated with forms of petty doctrinalism and intra-cultural battles that should not be allowed to take place in a tolerant, open and genuinely pluralist society? How can we be genuinely realist in believing that science aims at truth while at the same time being pluralist about science? Those who might share Aristophanes’ image of the philosophers counting the jump of the fleas on the floor might grin at this point: ‘Here we go: the philosophers are now mandating their directives about Truth in science and pluralism in society as if they had any authority or expertise to legislate on either.’

No, we do not have any authority or expertise to legislate on either. But who does? And if it does not fall upon philosophers of science to at least talk about such matters in public discourse, who should the task fall upon? Such matters cannot be left unspoken for they are too important. They cannot go unexplored because they impinge on any one of us, with wide-ranging consequences for society. The point is that truth matters (or should matter to science) as much as it matters in legal systems. Truth is an invitation to resist the temptation to question just for the sake of questioning. It is a commitment to get things right and to adhere to evidence as the only tribunal to which one should respond. In a culture where alternative facts seem to have made their way into media and public discourse in the name of some unqualified blanket pluralism, philosophers of science should stand up *with* scientists *for* science, and do so unabashedly, unequivocally and uncompromisingly. Recognizing that science is not a convenient expedient for political agendas and powerful lobbies; that scientific models are more than just useful tools to get things done; that scientific evidence—hard to harvest and difficult to interpret as it might be—is nonetheless still evidence (and the only real evidence) to abide by does not mean undermining pluralism in science or in society. Similarly, recognizing that our scientific knowledge is situated and perspectival, is always from a specific vantage point (that of the available instruments, conceptual resources and scientific practice of the time), does

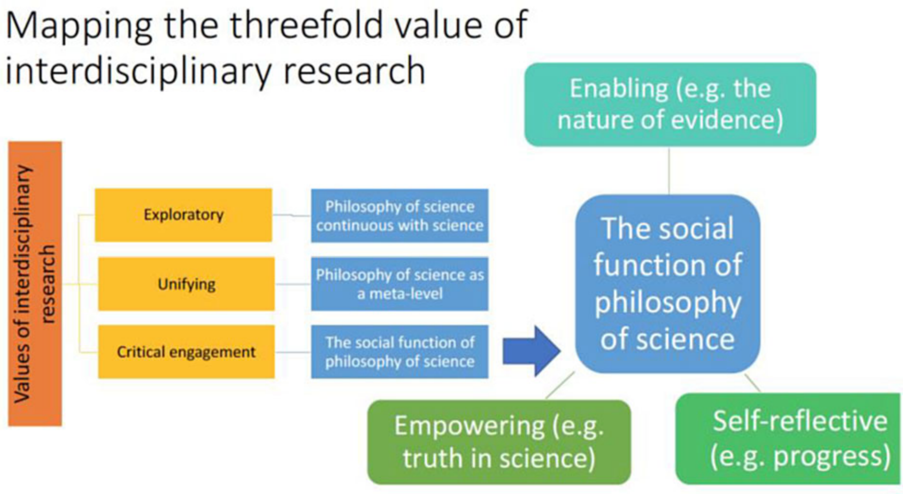


Figure 1. The threefold value of interdisciplinary research, and the related social function of philosophy of science. (Online version in colour.)

not make scientific inquiry any less realistic, or any less committed to finding out the truth about nature to the best that we can. This is what I call the *empowering role* in this three-vector social function of philosophy of science.

Over the past few years, I have been spending time studying some of these scientific practices and modelling techniques. I have benefited enormously from helpful conversations with colleagues in physics with an eye to better understanding how it is possible for us—finite human beings with the epistemic limits afforded by our perspectival knowledge—to go about exploring the unexplored; how it is possible to come up with new theories and models that—grounded and entrenched in our existing modelling practices—might nonetheless be used as probes to assess the available evidence and provide indications for new unknown physics beyond the Standard Model. Through this dialogue with working scientists, by studying some of their fascinating work and visionary practices, I have come to rethink the way in which truth, representation, perspectives and pluralism are typically portrayed in the literature. I believe that some traditional controversies about realism and antirealism in science originate from widespread philosophical assumptions about how models work, the relation between theory and evidence, and the role of representation in science. And I have been suggesting a novel way of thinking about these traditional issues, a novel way that has the potential of reconciling realism in science with pluralism and perspectivism. But this would be the topic of a research paper that I do not have the time to give here and so I refer the reader to my European Research Council project *Perspectival realism: science, knowledge and truth from a human vantage point* (http://www.perspectivalrealism.org), where the full list of academic publications is available (with a forthcoming monograph).

To conclude, there are many reasons why philosophy of science matters to science. These reasons have all got to do with the threefold value of interdisciplinary research (see figure 1). As I have highlighted, philosophy of science contributes to each and every one of these three main values: it contributes to the exploratory value by being continuous with science; to the unifying value by providing a meta-level where common methodological strategies can be evaluated; and to critical engagement by performing an important social function. Such social function is in turn articulated around what I have respectively called the enabling, self-reflective and empowering roles that philosophy of science plays for science.

Let me briefly return to Bernal and his portrait of the 'modern man before the man-made disasters of technological unemployment and scientific warfare, whereby the dangerous grip which demagogic fascist ideas can exercise is a measure both of popular ignorance and the need to have something to believe'.[35] Making the public aware of that plurality of perspectives does not mean anything goes, and does not mean that the evidence on one side is as good as evidence on the other side. Making the public appreciate that truth matters (in life as well as in science) and making the general public engage with these philosophical questions best serves the needs of democratic, tolerant and pluralist societies. It is this kind of interdisciplinary knowledge that empowers people to make informed decisions and responsible choices for themselves and for the future of their children.

## Acknowledgements

I thank James Upton for helping with the organization of this lecture, and Professor John Wood for chairing the event. Many thanks to Tim Holt and Anna Marie Roos for inviting me to contribute this article and for help with the editing. Themes and topics from this lecture are part of a project that has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement European Consolidator Grant H2020-ERC-2014-CoG 647272, *Perspectival Realism: Science, Knowledge, and Truth From a Human Vantage Point*).

## Notes

1 See I. B. Cohen, *Franklin and Newton: an inquiry into speculative Newtonian experimental science and Franklin's work in electricity as an example thereof* (American Philosophical Society, Philadelphia, 1956).

2 Hermann Boerhaave, *Elementa chemiae, quae anniversario labore docuit, in publicis, privatisque, scholis* (Isaacum Severinum, Leiden, 1732); Hermann Boerhaave, *Elements of chemistry: being the Annual Lectures* (trans. T. Dallowe) 2 vols (J. Pemberton *et al*., Printed for J. and J. Pemberton, J. Clarke, A. Millar, and J. Gray, London, 1735); Stephen Hales, *Vegetable Staticks: or, an Account of some Statical Experiments on the Sap in Vegetables: being an essay towards a Natural History of Vegetation. Also a Specimen of an attempt to analyse the air, by a great variety of chymio-statical experiments; which were read at several meetings before the Royal Society* (W. and J. Innys, and T. Woodward, London, 1727).

3 See Michela Massimi, 'Kant's dynamical theory of matter in 1755, and its debt to speculative Newtonian experimentalism', *Stud. Hist. Phil. Sci.* **42**, 525–543 (2011).

4 Andrew Janiak, *Newton: philosophical writings* (Cambridge University Press, Cambridge, 2014).

5 Isaac Newton, *Philosophiae Naturalis Principia Mathematica* (Joseph Streator, London, 1713; first published 1687); Isaac Newton, *The Mathematical Principles of Natural Philosophy* (rev. translation Florian Cajori) (University of California Press, Berkeley, 1934), p. 940.

6 English translations of all these texts have appeared in Immanuel Kant, *Natural Science: the Cambridge edition of the works of Immanuel Kant* (ed. E. Watkins) (Cambridge University Press, Cambridge, 2012).

7 Immanuel Kant, *Gedanken von der wahren Schätzung der lebendigen Kräfte und Beurteilung der Beweise, deren sich Herr von Leibniz und andere Mechaniker in dieser Streitsache bedient haben, nebst einigen vorhergehenden Betrachtungen, welche die Kraft der Körper überhaupt betreffen* (Martin Eberhard Dorn, Köningsberg, 1746); Immanuel Kant, 'Thoughts on the True Estimation of Living Forces', in Kant, *op. cit.*, (note 6), pp. 1–155; for a discussion of this text in the historical context of the time, please see Michela Massimi and Silvia De Bianchi, 'Cartesian echoes in Kant's philosophy of nature', *Stud. Hist. Phil. Sci.* **44**, 481–492 (2013).

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9 See Michela Massimi, 'Prescribing laws to nature', *Kant-Studien* **105**(4), 491–508 (2014); Michela Massimi, 'Grounds, modality, and nomic necessity in the Critical Kant', in *Kant and the Laws of Nature* (ed. Michela Massimi and Angela Breitenbach), pp. 150–170 (Cambridge University Press, 2017); M. Massimi, 'Laws of nature and nomic necessity: was Kant really a projectivist?', in *Proceedings of the XII International Kant Congress 'Nature and freedom'* (ed. V. Waibel and M. Ruffing) (De Gruyter, Berlin, in press).

10 See Gerard Holton, *Thematic origins of scientific thought: Kepler to Einstein* (Harvard University Press, Cambridge, MA, 1988; first published 1973), pp. 128–131 and ch. 7.

11 Albert Einstein, Boris Podolsky and Nathan Rosen, 'Can quantum mechanical description of physical reality be considered complete?', *Phys. Rev.* **47**(10), 777–780 (1935); Niels Bohr, 'Can quantum mechanical description of physical reality be considered complete?', *Phys. Rev.* **48**(8), 696–702 (1935).

12 Michela Massimi, *Pauli's exclusion principle. The origin and validation of a scientific principle* (Cambridge University Press, Cambridge, 2005).

13 Helen Longino, *Studying human behaviour: how scientists investigate aggression and sexuality* (University of Chicago Press, Chicago, 2013).

14 See, for example, E. LaRosa and D. Danks, 'Impacts on trust of healthcare AI', in *Proceedings of the 2018 AAAI/ACM Conference on Artificial Intelligence, Ethics, and Society* (in press).

15 See https://home.cern/about/updates/2017/12/forty-years-first-pet-image-cern (accessed 24 September 2018). I am very grateful to Marilena Streit-Bianchi for helpful conversations on this topic and reference materials.

16 Mary Hesse, *Models and analogies in science*, revised edn (Notre Dame University Press, 1966).

17 The ΛCDM model is the standard cosmological model, which postulates the existence of both dark energy (captured by Λ) and cold dark matter (CDM).

18 For example the Dark Energy Survey (DES), which is one of the largest ongoing cosmological surveys designed to search for evidence of dark energy, uses the Bayes factor along the Jeffreys scale to assess the evidence vis-à-vis two rival hypotheses, where the null hypothesis is the official ΛCDM model and the rival $H_1$ is a variation of ΛCDM model called *w*CDM, where the equation of state parameter $w$ is not fixed but is a free parameter. Thus, while *w*CDM shares with ΛCDM the six main cosmological parameters (e.g. the Hubble parameter, the matter energy density, etc.), it also has a seventh additional free parameter in $w$. Given two hypotheses $H_0$ (say ΛCDM) and $H_1$ (*w*CDM) and data set D, assuming equal flat priors for $H_0$ and $H_1$, the Bayes factor becomes the ratio of the posterior probability of $H_0$ to the posterior probability of $H_1$. In other words, the Bayes factor is a way of measuring the posterior probability of the evidence D *in favour of* $H_0$ (the null hypothesis in the usual Bayesian terminology, in this case ΛCDM) over the rival $H_1$ (*w*CDM in this case). How to interpret the numerical values of the Bayes factor $R$? DES adopts the standard Jeffreys scale (H. Jeffreys, *Theory of probability* (Oxford University Press, Oxford, 1961; first published 1939)), whereby $3.2 < R < 10$ is regarded as *substantial evidence* for $H_0$ over $H_1$ and, and $R > 10$ is regarded as *strong evidence* for $H_0$. Vice versa, $H_1$ is strongly favoured over $H_0$ if

$R < 0.1$ and there is *substantial* evidence for $H_1$ if $0.1 < R < 0.31$. See DES Collaboration, 'Dark energy survey year 1 results: cosmological constraints from galaxy clustering and weak lensing', *Phys. Rev. D* **98**, 043526 (2018).

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20 John Desmond Bernal, *The social function of science* (Routledge, London, 1939), pp. 88–89.

21 Madame du Châtelet was a French philosopher and scientist who translated Newton's *Principiæ* into French and in 1740 wrote the *Institutions de Physique*, an important text in the history of natural philosophy that influenced the young Kant. Her work has only recently been rediscovered thanks to Project Vox (https://projectvox.library.duke.edu) at Duke University.

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26 See, for example, Justin Khoury, 'Another path for the emergence of modified galactic dynamics from dark matter superfluidity', *Phys. Rev. D* **93**, 103533.1–14 (2016).

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28 Michela Massimi, 'Perspectival modeling', *Phil. Sci.* **85**, 335–359 (2018).

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30 For a contemporary overview on scientific realism, see Juha Saatsi (ed.), *The Routledge handbook of scientific realism* (Routledge, London, 2018).

31 For a brief overview, please see Michela Massimi, 'Perspectival realism', in Saatsi, *op. cit.* (note 30), pp. 164–175.

32 Thomas Kuhn, *The structure of scientific revolutions* (University of Chicago Press, Chicago, 1962).

33 See Catherine Elgin, *True enough* (Oxford University Press, New York, 2017).

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