1 Introduction

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This Companion provides an up-to-date overview of the philosophy of science, its central issues and its place in a wider disciplinary context. The essays in Part I, 'Philosophy of Science in Context', discuss the place of philosophy of science in relation to the rest of philosophy, to science itself and to the history of science. The essays in Part II, 'Current Research and Issues', cover many of the discipline's key debates as conducted today, both in general philosophy of science as well as in regard to particular sciences. Then, Part III, 'Past and Future', gazes ahead by reflecting on trends and new issues, emerging both from the contributions included here and also more generally. The whole volume is forward-looking in flavour, with the aim of indicating exciting new research that is 'hot' today, and probably even more so tomorrow. This forward-looking emphasis distinguishes the present Companion from the other companions and encyclopaedias on the market. For the sake of completeness and for the volume to serve as a study aid, there is also 'A Brief Chronology of the Philosophy of Science', and Part IV, 'Resources', that includes 'A-Z of Key Terms and Concepts', 'Annotated Bibliography', and 'Research Resources'.

Before we turn to an overview of the individual chapters and some of their interconnections, a few general words about philosophy of science and its disciplinary status are in order. As a discipline in its own right, it is a comparative newcomer, emerging with its own journals, conferences and so forth only in the past 80 years or so. However, its roots go back much further, in scientists' own reflections on what they were doing and also in the fact that many philosophers, ever since Aristotle, have taken science to fall within their purview.[1] Broadly speaking, philosophy of science covers issues such as the methodology of science, including the role of evidence and observation; the nature of scientific theories and how they relate to the world; and the overall aims of science. It also embraces the philosophies of particular sciences, such as biology, chemistry, physics and neuroscience, and considers the implications of these for such issues as the nature of space-time, the mind-body problem, and the foundations of evolution.

Throughout its development, its relationships with other disciplines and research programmes, both in philosophy and in the history of science, have

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been under scrutiny. For example, in the mid-1980s, the philosophy of science was described to one of us as being in a state of degeneration and as being fractured into inward looking cliques and sub-disciplines. It was even strongly suggested that anyone seeking to do productive research in philosophy should look elsewhere. The grounds for such an uncompromising view lay with the belief that the 'new directions' for philosophy of science – indicated by Suppe in his magisterial overview from 1977 (Suppe 1977) – had effectively run into the sand. In that work, Suppe set out both the shift away from those perspectives on science associated with the logical positivists, and also the rise and fall of the views of Kuhn and others that emphasized both the importance of the history of science and the purported role of social factors. In their place, Suppe envisioned that there would emerge a philosophy of science based on a robust form of realism that asserts that we can have knowledge of how the world 'really is' and that observation, experiment and the methodology of science play a fundamental role in obtaining that knowledge. It was this realism – shaping it, developing it, exploring its metaphysical and epistemological underpinnings – that became the focus of much work over the subsequent decade or so. No longer were philosophers of science attempting to demarcate science from pseudoscience, or presenting grand, large-scale methodological frameworks which they could use to tell scientists how 'good' science should be done. Instead, they became preoccupied with what appeared to those outside the field to be minor issues and problems, or were locked into particular and sometimes highly technical subfields, such as the philosophy of physics.

At the same time, the rejection of views that tried to place science in its historical as well as sociopolitical contexts brought in its train a turning away from the history of science. Historians of science, for their part, contributed to what came to be seen as the divorce of the two disciplines by focusing increasingly on the above contexts, to the exclusion of the 'internal' forces that philosophers were concerned with, having to do with evidence and its relationship to theories. By the early 1990s this division had become so wide and so entrenched that concerns were raised on both sides and meetings were held to analyse the causes and consider whether bridges could still be built between the two sides (see Steinle and Burian 2002).

Furthermore, despite hopes that the examination of the practices of science would have profound implications for metaphysics and epistemology, the philosophy of science has also seemed to be ploughing its own distinct furrow with only minimal contact with other, hugely significant areas of philosophy. Metaphysics, for example, has experienced a major resurgence in recent years, with exciting new research undertaken on a wide range of topics, such as modality, mereology, the nature of time and so on. It has even generated a new sub-discipline, meta-metaphysics, which examines, for example, whether

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metaphysical questions have determinate answers, and if they do, what methodology one would use to choose one metaphysical system over another (see Chalmers et al. 2009). But while all this activity has been going on, the concerns of metaphysicians and the metaphysical views they espouse have come to seem increasingly distant from those of philosophers of science and, indeed, from any grounding in science itself. Metaphysical discussions of the ontological nature of things, for example, have proceeded with little or no consideration of what current science tells us about those things in their most fundamental form. Even where there are obvious points of contact, the two fields seem to be moving along different trajectories: recent metaphysical accounts of scientific laws, for example, appear to rely on some naïve conceptions based on simplistic 'toy' examples and make little, if any, mention of conservation laws and symmetry principles which, it can be argued, are just as fundamental for modern physics. This situation has led some to decry contemporary metaphysics as either divorced from science altogether or, at best, paying it only lip service (Ladyman and Ross 2007).

Although less pronounced, one can detect a similar tension between philosophy of science and epistemology. The latter is concerned with the study of knowledge in general and justified belief in particular. In contemporary discussions, a division has appeared between those that regard the justification of belief, and hence knowledge, as depending on internal factors, such as reflection on one's own cognitive processes, and those that hold it to depend on factors external to us that originate in reliable processes, say. The philosophy of science, on the other hand, is (not surprisingly) more focused on the practices of science, some of which can be understood from an internalist perspective, while others seem more amenable to an externalist understanding. Although science is often held up as the 'paradigm' of knowledge-gathering activity, there has been surprisingly little engagement with these practices by epistemologists, and philosophers of science, in turn, have tended not to draw on general epistemological accounts as extensively as they might. The situation is undoubtedly unsatisfactory for both fields, and there is a clear need for a more positive and productive interaction.

So, when it comes to those three areas with which the philosophy of science might be expected to have the closest contact – the history of science, metaphysics and epistemology – significant rifts and divisions have appeared in the last 30 years. In each case, these have hampered work on both sides. However, recent developments have brought signs of hope and indications of new directions opening up.

Thus, the history of science is being engaged again, not only through award-winning books such as Chang's account of the measurement of temperature (Chang 2004), or Ryckman's acute analysis of disregarded views of Einstein's general relativity (Ryckman 2007), but also by means of

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interdisciplinary interactions between history and philosophy of science and science studies, and the international conferences of the '&HPS' movement.[2] **Don Howard** has played a leading role in these developments, and in his essay for this collection he maps out the history of the changing relations between the history of science and the philosophy of science. After providing a rich historical overview of the earlier close and productive relations between the two, Howard examines the role played by philosophers themselves in the divorce. Here we face a puzzle: it is usually the logical empiricists who are blamed for the split, but they themselves embraced serious history of science scholarship. Howard draws on the underlying political machinations to provide an answer. Although the 'left wing' of the Vienna Circle espoused both the value-ladenness of science and the importance of the history of science for the philosophy of science, it was the 'right wing' that gained the ascendancy. Through the promotion of the distinction between how theories are discovered and how they are justified – with philosophy of science to be concerned only with the latter – it pushed out values and denied the philosophical relevance of 'real', as opposed to reconstructed, history.

Howard also considers how we got to where we are now, with renewed interest in the history of the philosophy of science and, following the demise of logical empiricism, a new willingness to engage with the history of science. Friedman's now classic work, *Kant and the Exact Sciences*, is taken as representative of this engagement, as it seeks to construct a framework that both respects the 'historicity' of science and also avoids the cheap kind of relativism that comes from insisting 'different era, different science, different methodology'. This is not the only framework in town, of course, and the interest in appropriately capturing and advancing the 'HS' and 'PS' relationship is another indication of the health of the discipline.

The relationship between philosophy of science and metaphysics has long been fraught. **Craig Callender** has spent much of his career working on the metaphysical implications of modern science, particularly physics, and in his contribution he recalls the point made above that, as philosophy of science has moved closer to science, metaphysics seems to have drifted further away. His own view is that although metaphysics is deeply important to, and 'infused within', science, many current debates within this area of philosophy are sterile or even empty. In response, metaphysics needs to become more responsive to and connected with current science, just as its importance for science must be emphasized, particularly when it comes to explanation and understanding. As he notes, his provocative but thoughtful essay is a largely negative critique, but clarifying what is wrong with the current situation is necessary if we are to move forward. Thus, consider modality, for example—the study of possibility, necessity and the like. As Callender points out, metaphysicians often rely on intuitions in developing views of modality, yet these intuitions

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are historically conditioned and may be unreliable, or even inconsistent. Instead, and more positively, he urges that our understanding of what is possible or necessary should be more closely tied to what science tells us, and that we should take such modalities only as seriously as the theories that generate them. This is a contentious line to take, but if metaphysics is not to become entirely intuition driven, or tied to scientific theories that were abandoned hundreds of years ago, it is a line that at least needs to be considered. Callender sums his position up in a slogan that appropriately reflects this new relationship: metaphysics is best when informed by good science, and science is best when informed by good metaphysics.

As we also noted above, philosophy of science, not unnaturally, tends to focus on the practices of science – a tendency that **Alexander Bird** calls 'particularist' – whereas epistemology offers a much more general account of knowledge and justification. Bird illustrates some of the difficulties in resolving these tensions by looking at the cases of Bayesian confirmation theory and inference to the best explanation (IBE). The former gives us a rule (Bayes' Theorem) that tells us how we should update the probability of a hypothesis given the evidence, where such a probability is traditionally understood in terms of subjective degrees of belief. Because the formalism of Bayesian confirmation is that of probability theory, the rationality of updating one's beliefs in this way is established via 'internal' factors, rather than, say, empirical investigation. IBE, on the other hand, is more restricted in scope, but licenses the truth of a hypothesis on the grounds of its providing a better explanation than its competitors. Its reliability depends on 'external' considerations, most particularly the existence of a correlation between truth and good explanations. Thus, Bayesianism and IBE relate to different tendencies within epistemology, and Bird outlines the problems with these, before emphasizing how a 'naturalised' approach allows a role for science to play in epistemology by setting our cognitive capacities in the appropriate evolutionary context. He concludes by pointing to recent work on 'knowledge first' epistemology, where there is significant potential for productive interaction with the philosophy of science.

Turning from these broader issues and concerns to the more narrowly focused topics found in Part II, 'Current Research and Issues', here, too, new developments and directions of research can be discerned. Indeed, by the time the claim that the philosophy of science was degenerate had been made, the realist consensus indicated by Suppe had been shattered by the publication in 1980 of van Fraassen's classic work, *The Scientific Image* (van Fraassen 1980), which presented a plausible form of anti-realism based on empiricist principles. Taking the aim of science to be empirical adequacy, rather than truth, van Fraassen has subsequently developed an entire 'empiricist stance', that extends from the foundations of quantum physics to the nature of scientific representation.

Stathis Psillos is notable for presenting a robust realist response to this anti-realist tendency. In his chapter for this volume he both sets the debate between realists and anti-realists in the context of its rich historical legacy and examines the twists and turns of the debate itself. Thus, following the publication of van Fraassen's book, there has been an increased focus on finding a principled way of distinguishing those parts or aspects of the world that we can know from those that we cannot. Psillos takes the drawing of such a distinction in a principled way to unite the constructive empiricist, such as van Fraassen, with various realists, such as the (epistemic) structural realist and the 'semi-realist', but he argues that there is, in fact, no good reason to draw such a distinction in a principled way, and hence no need to abandon standard scientific realism. In addition, there has been a further shift towards the incorporation of neo-Aristotelian metaphysics into these variants of realism, and here again we encounter some of the issues discussed by Callender. According to Psillos, such moves can create a tension with the desire to draw the above distinction, and in any case, these shifts to neo-Aristotelianism should be resisted in favour of a less extravagant metaphysical landscape that draws its inspiration from the empiricist philosopher David Hume.[3]

The notion of explanation features prominently in the realism debate. Realists think science explains things about the world – facts, phenomena, the data obtained through experiment – and that the explanatory power of theories is an indicator of their truth, while anti-realists regard such power as purely pragmatic. But whatever stance is taken, an understanding of scientific explanation is crucial. **Henk de Regt** presents an overview of different accounts of explanation, covering both those that emphasize causal relationships (and that appear in a number of the essays included here) and those that are relevant for the human sciences. Importantly, he explores the adoption of a pluralist stance with regard to explanation and notes that, on the one hand, from a pragmatic perspective, explanation can have different forms in different contexts, and, on the other, if understanding is taken as a universal aim of science, this can be achieved via different modes of explanation that vary according to context. Furthermore, de Regt insists, these two approaches are not necessarily incompatible. As he says, science itself is varied, and so we should respect the diversity of models of explanation. He concludes by tying his discussion in with many of the themes covered elsewhere in the volume and noting some directions for future research, particularly with regard to mechanistic models.

As de Regt notes, causal accounts of explanation are currently very much in vogue within the philosophy of science. But when attempts are made to spell out the notion of causality, we once more run up against the kinds of concerns indicated by Callender. It would be so easy if philosophers of science could take such a notion down off the shelves of metaphysicians, but the

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latter's debates seem driven by unscientific 'intuition pumps' and series of examples and counter-examples that appear to have little, if anything, to do with current science. **Ned Hall** acknowledges this in his paper on causation, but he takes a more conciliatory line, urging us to take the metaphysicians' intuitions as clues that indicate where more fruitful concepts of causality might be found. Furthermore, he notes that although the metaphysicians' obsession with singular causation may appear to be less interesting in a scientific context, these discussions may act as 'seeds' around which more interesting kinds of questions can crystallize. In particular, they may help us get a grip on the kinds of counterfactual claims that underpin the understanding of causal structure as a structure of dependencies. This is where an account of laws comes into the picture, and Hall delineates the two current rival accounts and their variants. It is in explicating these issues in the scientific context that we can see the potential for productive and fruitful interaction between the philosophy of science and metaphysics.

Moving from metaphysical to epistemological matters, one central question – dealt with by **James Hawthorne** in his essay on confirmation theory – is how can we come to know whether the claims of science are true? A theory of confirmation takes the relevant evidence and, on that basis, effectively tells us the extent to which a given hypothesis is confirmed. The most influential contemporary theory of confirmation is Bayesianism, which uses probability theory – in the form of Bayes' Theorem – to express how the likelihood of the evidence given the theory (that is, how likely the evidence is) contributes to the extent to which that theory is confirmed by that evidence. Although this area can quickly become very technical, Hawthorne presents all the relevant details in a clear and succinct fashion. He also considers the issue of what these probabilities represent, noting that the traditional view (discussed by Bird), that they express subjective degrees of belief, runs into considerable difficulties. His own view is that we should stop trying to give an account of what they are and think about what they *do*. Here the answer is clear: they are 'truth-indicating indices', and conceiving of them this way suggests a pragmatic strategy of continually testing hypotheses and taking whichever has an index closest to one as our *best current candidate* for being true.

Scientific evidence, on the above account, enters only with regard to the expression for the likelihoods that feature in Bayes' Theorem. Hence **Malcolm Forster**, in his chapter on evidence, refers to it as the 'likelihood theory of evidence'. However, in his contribution he urges the adoption of a broader conception, drawing on work in epistemology, and presses the point that the goal of our accounts of evidence should encompass not just the truth of theories, but also their predictive accuracy. Even if this is only a transitional step towards truth, it is a hugely important one; in some cases, optimizing truth need not involve optimizing predictive accuracy, and vice versa. Attempts to

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understand science in terms of a single goal may thus be doomed to failure, and Forster argues for a more nuanced understanding of the relationship between such different goals.

Furthermore, whether scientific theories should be thought of as being truth-apt to begin with is itself a problematic issue. One of the most significant trends over the past 40 years or so (flagged by Suppe in his 1977 volume) has been an emphasis on the nature and role of models in science. In his contribution on models and representation, **Gabriele Contessa** outlines these developments, focusing on the way in which such models *represent*. In this case, it is the philosophy of art that has been turned to for both the relevant frameworks and the supposedly pertinent examples, with work in this area spanning the realism–anti-realism divide (see, for example, van Fraasen 2008). Contessa notes how such representational models allow us to engage in 'surrogative reasoning' about the systems of interest and draws an important distinction between the issues of what makes something a scientific representation and what makes it a 'faithful' representation. This allows him to impose a certain order on recent debates between alternative accounts and, in particular, he argues that although representation comes quite cheaply, faithfulness is a more costly commodity. He also considers the important question, whether any difference can be found between scientific and non-scientific representations, and answers that there appears to be none, although the former will obviously place greater emphasis on the quality of being faithful.

Realism as a stance within the philosophy of science is also influenced by developments in the foundations of the sciences – as described by the philosophies of those particular sciences – and it sometimes feeds into these philosophies as well. Van Fraassen's anti-realism, touched on above, was motivated in large part by concerns over the impossibility of maintaining appropriate forms of realism with regard to quantum physics and the foundations of spacetime. Philosophical reflection on these topics has flowered over the past 30 years or so, and the results that drove van Fraassen to anti-realism have now been reinterpreted in ways that are more amenable to at least some forms of realism. Presenting these results in an accessible way is a difficult task, but **Nick Huggett** has managed to do so, while also presenting an overview of the foundations of statistical mechanics, a topic that has recently become the focus of considerable interest. Thus, he covers recent discussions of the statistical grounding of the Second Law of Thermodynamics, which he takes to provide an arrow of time, but one that is minimal and non-fundamental. Huggett also examines the metaphysical implications of quantum statistics for the identity of indiscernibles and explores the differences between the geometrical and dynamical approaches to General Relativity, concluding with a note on its cosmological implications.

However, the philosophy of science has long been held to be too 'physicocentric', a feature that can be explained on historical grounds, but which has

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been seen as closing off the opportunity to garner both useful insights and alternative stances from other disciplines. The philosophy of biology has only emerged from this shadow in the past 40 years or so, but has rapidly established itself as very much a practice-oriented field, where there is fruitful interaction between biologists and philosophers. As **Ingo Brigandt** notes, the issues that have arisen have been both epistemological and metaphysical, and in addition to ongoing discussions pertaining to evolution, molecular and experimental biology have also recently moved into the spotlight. As in the case of the philosophy of chemistry, to be touched on below, issues of reduction and explanation arise, in association with biological case studies, that have significant relevance for the philosophy of science in general. Thus, whereas in the latter, different accounts of explanation may be seen as rivals, within the philosophy of biology they are typically seen as complementary, a view that chimes with de Regt's suggestion above. And here we find models of explanatory reduction that are better suited to the piecemeal nature of practice in biology itself.

Similar issues arise in the philosophy of chemistry, which is another area that has grown in interest and where considerable work has been undertaken in articulating what it is that is distinctive about this field. Here **Robin Hendry** focuses on conceptual issues having to do with substances, bonds, structure and, again, reduction. A common thread running through his discussion concerns the importance of bringing scientific practices to bear on philosophical issues and debates. Thus, it is notable that philosophical considerations of 'water' as a term denoting a natural kind, for example, typically proceed with little input from chemistry. There are also foundational issues particular to this field, such as those having to do with the appropriate characterization of chemical bonds, which have been comparatively little discussed. Reduction, on the other hand, has long been a central topic, both in the philosophy of chemistry and the philosophy of science in general. Here Hendry covers a number of important distinctions, most notably that between the reduction of one theory to another and ontological reduction, that is, from one set of entities to another. In the latter case, he notes, the possibility of emergent properties and sui generis chemical laws raises interesting issues and, of course, the potential for blocking moves to establish any kind of straightforward reduction between chemistry and physics.

The issue of how to characterize scientific reduction in general is covered in detail by **Sven Walter** and **Markus Eronen**. In their overview of attempts to develop an appropriate account, they draw on examples from the philosophy of mind and from neuroscience. They note, in particular, the shift from the supposed derivability of a given theory from a more fundamental one, to an appreciation of the practice of science where scientists mount explanations in terms of empirically discoverable mechanisms. These explanations are typically 'multi-level' and present both a 'downward-looking' and an 'upward-looking'

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aspect that has been taken to support both anti-reductionistic (and pluralistic) and reductionistic attitudes. Here, metaphysics can again find useful employment in providing an appropriate underpinning for the crucial notion of 'level', but in an area such as neuroscience and in the context of an emphasis on mechanism, that notion must be understood as local and case specific. Here, as Walter and Eronen indicate, there is considerable scope for future research.

Mechanistic explanations also feature prominently in **Carl Craver** and **David Kaplan's** discussion of neuroscience, in which they defend the legitimacy of such explanations from top to bottom, as it were. Their distinction between 'good' and 'bad' explanations in terms of the revelation of causes meshes with neuroscience's emphasis on control, rather than expectation or prediction of empirical results. This distinction then allows them to sort the various kinds of models one finds in this field, and it also underpins their argument that merely descriptive models have little, if any, explanatory value. In neuroscience, at least, explanation is a matter of situating neurobiological phenomena within the causal structure of the world, and hence we return to issues concerning causality covered by Hall.

These issues also crop up in Jaakko Kuorikoski and Caterina Marchionni's essay on the philosophy of economics. The authors map the shift from the earlier unified and axiom-centric view of economics as capturing the relevant causal factors to more recent accounts that emphasize game-theoretic tools on the one hand, and the role of empirical testing on the other. They also note the fragmentation of methodology and the increasingly porous nature of the boundary between economics and the philosophy of economics. Again, the role of models achieves considerable significance on this view, with game theoretic models exemplifying typical cases and economic theory acting only as a kind of 'template' at best. Experimentation is then seen as less about testing some core theory and more to do with helping to formulate local causal hypotheses about economic phenomena. Thus, Kuorikoski and Marchionni's conclusion is that rather than taking economics to possess some kind of 'unifying core' that gives us (causal) understanding of the world, we should regard it as a generalization over families of models that helps to organize cognitive work and facilitates communication between workers in the field. The scientific image it presents is one they call 'Babylonian' in its heterogeneity, diversity and openness.

Finally, although mathematics is clearly an area in which a focus on causal factors would be inappropriate, nevertheless issues of explanation and modelling arise here, too. As **Christopher Pincock** records, for many years now there has been a distinct separation between the philosophy of mathematics and the philosophy of science. In some respects, this parallels the separation, decried by Callender, between metaphysics and the philosophy of science,

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with the philosophy of mathematics focused almost exclusively on matters of ontology. However, the recent attention paid to mathematical practice has engendered a form of rapprochement, as issues to do with epistemology and explanation, for example, come to the fore. Even more interestingly, perhaps, there has been close examination of the role that mathematics plays in science. This has generated another realism–anti-realism debate, now centred on the issue of whether the apparent indispensability of mathematics in science licenses a realist attitude towards the relevant mathematical entities. Pincock covers both sides of this debate, taking us through the latest developments, before concluding with a consideration of the role of mathematics in modelling and idealization. As he says, these issues place the role of mathematics firmly on the philosophy of science agenda.

We hope we have indicated here the various threads that run through the contributions to this volume, from particular concerns with causal explanations, reduction, representation and so on, to more general and, perhaps, more fundamental issues regarding the relationship between the philosophy of science and metaphysics, epistemology and also the history of science. Our aim in selecting both the topics of the essays and their authors was both to provide overviews of these ongoing discussions and also to indicate the new directions and research trajectories that have emerged in the past few years. We shall return to these in our essay 'Travelling in New Directions', but our further hope is that the reader – whether an undergraduate student taking her first course in the philosophy of science or the hardened veteran of these debates – will find something useful, interesting and thought-provoking in these essays.

Notes

1 The 'Chronology' charts some of the history here.
2 For a light-hearted account of the first conference of this new movement, see http://bit.ly/azkycm
3 Hume's ideas also feature prominently in Hall's essay on causation.

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