THE NEVER-ENDING DANCE OF PHILOSOPHY AND PHYSICS

Nick Huggett, UIC

Joshua Norton, UCI

We are both philosophers of physics. As such, we often find ourselves explaining to puzzled faces, on family, friends, students, strangers on trains, even colleagues on occasion, what physics (which rests on experiment) has to do with philosophy (which apparently does not). It's a fair question. We'd like to take this opportunity to answer it by considering some examples in which physics affects philosophy; and then examining how this is possible. We hope that by the end, it will be clear that physicists and philosophers can both benefit greatly from working together.

1. Philosophy and the Scientific Revolution

• Descartes and physical explanation:

Examples of the influence of physics on philosophy can be multiplied throughout history, but ours are drawn from the seventeenth century, a time of rapid social and political change in Europe, and the time of the so-called 'scientific revolution'. The French philosopher René Descartes (1596-1650) is famous for his philosophy ("I think therefore I am") and his mathematical contributions (our Cartesian coordinates). He was also deeply involved in the historical currents of his time: as a young man he served in the Dutch army; the 1633 condemnation of Galileo led him to leave a manuscript defending Copernicanism unpublished; his most famous philosophical works were read widely by a public audience; his physical ideas were so influential that Newton consciously opposed them; and he corresponded widely with intellectuals and royalty — indeed, he died during a visit to Queen Christina of Sweden. Not surprisingly, these experiences influenced his philosophical investigations.

Understanding Descartes' philosophy in historical context requires understanding the long Aristotelian tradition that he was challenging, modifying, or accommodating, by turns. In particular, many of Aristotle's explanations of natural phenomena in his book the *Physics* rely on identifying a natural *end* or '*telos'* to a process: for instance, the growth of a seed into a flower. For

Aristotle things naturally tend towards their ends, and such tendencies explain changes: the seed grows *in order to become a flower*, rather than because biological and chemical laws cause it to. Or again, heavy objects like rocks fall in order to sit as close to the center of the universe as possible, while the stars and (non-terrestrial) planets have as their *telos* rotation about the center – a picture that places the Earth at the center, with the stars and planets in orbit around it. Contrast this account with Newton's, in which motions are explained by gravitational attraction, not ends.

But Aristotle's 'teleological' scheme is flawed because it makes explanation too easy and hence uninformative. All we have said is that seeds grow because they have the power of growth, that rocks fall because they have the power of falling – or, in Molière's ridiculing example, that opiates cause drowsiness because of their 'dormitive' powers. By the middle of the seventeenth century, it was realized that merely ascribing the power to achieve an end was an inadequate analysis, a realization that helped drive the scientific revolution. (Even more important was the failure to turn the Aristotelian theory of motion into a precise description of the motions of the planets. The historian and philosopher Thomas Kuhn's, *The Copernican Revolution*, tells the story beautifully.)

In place of Aristotelian teleology, Descartes articulated a 'mechanical' philosophy, of which we will consider two features. First, there is a focus on the most basic properties of matter. Introductory philosophy courses often study an argument concerning a lump of wax, which appears in the second of Descartes' *Meditations on First Philosophy*. (This book asks how we can obtain knowledge for ourselves, rather than simply relying on 'received wisdom' — Aristotle's teachings for Descartes, but the question is important for all enquiring minds.) He points out that the wax's perceived features can change: at different times it has a different smell, color, texture, and so on. He concludes that we cannot simply take on faith that our perceptions show the basic nature of the wax (or any other object): does it smell of flowers or not, look, white or yellow, feel soft or hard? Descartes' solution to this quandary is that our minds have a God-guaranteed facility to discriminate those perceptions which are 'clear and distinct', and hence provide reliable knowledge.

In later meditations he argues that the only properties of the wax which we so perceive 'clearly and distinctly' are its shape, volume, and motion; while other, such as smell, color and texture, remain uncertain. However, Descartes does not pluck these properties from thin air: in the physical theory found in his *Principles of Philosophy*, Descartes claims that they are the ‘essential’ or defining properties of matter. In his account, the physical world is composed of material objects with no properties but their shapes, volumes and motions. All other perceptions, like smell, color and texture, are explained 'mechanically' by the effects of the shapes, arrangements and motions of things on our senses. In short — and this is the important point — Descartes’ philosophical conclusions regarding knowledge of matter are in lock-step with his mechanical theory of the physical world.

Mechanical explanations are 'reductive': all physical properties and processes are to be reduced to the arrangement and rearrangement of matter, not explained teleologically. For instance, Descartes believed that the planets were carried in their orbits by a cosmic fluid, and not to realize an Aristotelian telos of circular motion. Indeed, he explicitly rejects teleology in the fourth mediation, because it would require knowing God's intentions.

But his alternative would be incomplete without an account of how matter moves, which brings us to the second feature of the mechanical philosophy, Descartes' laws of motion. They do not ascribe Aristotelian *future* ends, but instead specify how things will move given their *current* state. For instance, there is a natural tendency to remain in constant motion in a straight line, while collisions cause rebounding in a regular way. Following these laws is supposed to produce the orbits of a planet as it is pushed by the particles of cosmic fluid. The crucial point here, however, is that Descartes’ rejection of teleology fits his physical laws, just as his views on the knowability and nature of matter match. *In both cases his philosophy matches his physics.*

• Newton and Leibniz on motion and action:

In 1717, Samuel Clarke (1695-1729) published a series of letters that he had exchanged with Gottfried Leibniz (1646-1716), concerning the coherence and implications of contemporary science, especially that of Isaac Newton (1643-1727). Clarke was an important philosopher and theologian, and famously a defender of Newton: indeed he was Newton’s friend, and the rector of a church that Newton attended. (It's also important to know that Clarke shared drafts of his letters to Leibinz with Newton for his comments.) Leibniz was a prolific and famous polymath: philosopher (claiming that this is the “best of all possible worlds”), mathematician (claiming honors with Newton for the discovery of the calculus), theologian, historian, inventor, and much more. The political backdrop to their correspondence was the turmoil of seventeenth century Europe: in Britain civil war, Protectorate, Restoration, Glorious Revolution, and eventually the succession of George I in 1714. In the following year, Leibniz, seeking to ingratiate himself with the court that George brought with him from Hannover, wrote to his daughter-in-law, Princess Caroline, criticizing Newton for causing the decay of 'natural religion' in England. Caroline passed on part of the letter to Clarke, whose reply she in turn sent in turn to Leibniz: eventually nine letters passed between them in this way, and a tenth was written by Clarke after Leibniz's death.

Once published, in English, French, and German, the *Correspondence* was read and debated enthusiastically. Like Descartes' *Meditations*, one should not think of it in historical context as a specialist academic text, but rather as a serious work by public intellectuals, raising important issues of general concern. The central issue, as Leibniz indicated, is that of natural religion: the place of God in 'natural philosophy', or science, as we would say today. Much of the discussion concerns Newton's *Mathematical Principles of Natural Philosophy,* or *'Principia'*. (Even the title is a response to Descartes' *Principles*: emphasizing the need for more mathematical precision and responsibility to natural phenomena than Descartes provided.) Before we can talk about the *Correspondence* then, we need to understand some Newtonian background.

Newton adopted Descartes' mechanical law concerning the natural tendency of objects as his first law, that of ‘inertia’: a body remains at rest or continues at the same speed in a straight line, unless forces act on it. But what exactly does it mean to move in a straight line, or to have a constant speed? We are used to making such judgements relative to the Earth – for instance, on the speedometer of a vehicle. But relative to different standards we get different answers: objects at rest on the Earth move in an ellipse around the Sun, for example. Newton argued that Descartes' law requires a unique standard of motion: whether a force acts is not relative, so it cannot be relative whether a body moves in a straight line or not. Thus he proposed an account of space and time according to which they are 'absolute': space is an unchanging 3-dimensional arena in which matter is located and time ticks off uniformly, regardless of what rulers or clocks we use to measure them. These ingredients certainly makes sense of the law of inertia: without forces, a body remains at the same point of absolute space, or moves in a straight line through absolute space, across the same distance every absolute second.

However, absolute space and time are not directly observable, so how is one supposed to determine how a body moves absolutely? For Newton the question was critical – indeed he tells us that answering it is the purpose of the *Principia*. For although the Copernican, heliocentric account of the solar system was generally accepted, it still had live competitors, especially the 'Tychonic' account, in which the Sun orbits the Earth, and the other planets orbit the Sun. The Tychonic and Copernican systems have exactly the same relative motions, so the question of which is correct only makes sense with respect to a background such as absolute space. Newton showed that his second law, that acceleration with respect to absolute space is proportional to force (and inversely proportional to mass) settles the question. According to the second law, the Copernican system is correct because the gravitational forces between the planets and Sun entail that the planets obit the Sun in absolute space. Of course, such an answer requires knowledge of how strong the forces are. So the *Principia* is famous for Newton's empirical derivation of the law of universal gravitation: that every single particle of matter in the universe attracts every other in virtue of its mass.

We will discuss just two of Leibniz's criticisms of Newton from the *Correspondence*. First, against absolute space. Since it is uniform, there is no reason to locate the universe at one absolute place rather than another: two feet to the right would be just as good. So if God created absolute space He would be faced with a choice – selecting the actual place of the universe – with no 'sufficient reason' to decide one way or the other. Leibniz said, however, that as God is reasonable He must have a sufficient reason for any choice: so he would not create absolute space, with its unsolvable dilemma. Clarke responded that God is, on the contrary, able to simply pick between equivalent options, since His powers are unlimited; and if He has a reason to pick, then He is reasonable. The debate about whether choice between equals is reasonable continues through the letters, and both sides raise additional arguments. For instance, Newton postulated that the universe as a whole is at rest, but acknowledged that we would not be able to tell if it were moving at a constant velocity in absolute space. Leibniz claims that such unobservable differences are unreal – and would present God with another impossible choice between equals. Clarke retorts that Leibniz is committed to the view that God cannot move the whole universe (a heresy prohibited by the 1277 *Condemnation of Paris*). And so on.

The second issue concerns universal gravitation. Because it acts at a distance, Leibniz claims gravity is 'supernatural', hence unscientific. He takes the Cartesian view that the only kind of physical action is between colliding bodies: for Descartes and Leibniz, the motions of the planets are explained by a fluid rotating about the Sun, carrying them around with it, and not by Newton's gravity. Clarke responds that calling something 'natural' just means that it is the usual state of affairs — and what could be more usual than *universal* gravity?

In both these examples it is clear that Newton's proposed physics is driving philosophical investigations: what is the role of God in nature? What is it to choose? Must physical laws involve only local interactions? What is it to be natural? So the situation is as we saw for Descartes: philosophical debates are strongly intwined with the physics that was developing at the time. Of course, much of what was said may seem quaint or wrong-headed today, but they were pressing issues of the day for those trying to understand the broader implications of the new science.

Moreover, these debates are part of a much longer history of engagement between physics and philosophy. Newton's conscious critique of Descartes' methodology spurred mathematical and empirical science; his reflections on the relation between space, time and their measures are an ancestor to Einstein's arguments for relativity. Leibniz's thoughts on the indistinguishability of different states of motion are ancestors of the principle of relativity; and his critique of action at a distance is an early example of a principle of 'locality'. And so on. In short, the development of physics has been a major source of philosophical impetus as new concepts need to be understood, and old ones are replaced.

2. Quantum Gravity

But that influence on philosophy is not just a thing of the past – it continues today. A clear example of how contemporary developments in physics affect philosophy is found in theories of 'quantum gravity'. Let us explain.

Physicists tell us that there are four fundamental forces: gravity, electromagnetism, and the strong and weak nuclear forces. In the 1950s, electromagnetism was 'quantized' and, by the late 1970s, both the weak and strong forces were also given quantum mechanical descriptions. The only force that has not yielded a quantum description is gravity. What it precisely means to quantize a theory, or its associated forces, is not cessential here. But physicists generally believe that the true description of gravity will also be a quantum theory, and not the 'classical' theory of gravity that we currently have. (Lee Smolin's *Three Roads to Quantum Gravity* is an excellent starting place on this point, and for further reading). If successful, such a theory would, for instance, explain some of the strange events happening inside of blackholes (imaginatively explored in the recent film *Interstellar*). However, the final form of such a theory is not yet known; instead there are competing incomplete proposals, of which we will consider two.

Our theory of classical gravity is no longer Newton's universal gravity, but Einstein's general relativity, which tells us that gravity is not a force but the effect of motion in space and time with a curved geometry (again, Smolin is an excellent introduction). Our first example of a proposed theory of quantum gravity, 'loop quantum gravity' (or 'LQG') thus attempts to provide a theory of quantum gravity in the form of quantum geometry. In relativity a mathematical object called the 'metric field' encodes all the geometric properties of spacetime: lengths, areas, volumes, and times. But to quantize gravity, LQG tosses out the metric field in favor of objects called 'spin-networks'. And without the metric, LQG, in general, does not have the geometry required for spacetime. But all is not lost, spacetime might yet be found.

Without going into detail, it is helpful to compare spin-networks to a set of lego bricks (though 'fuzzier'). Lego bricks can be arranged in various ways: a messy pile on the floor, a castle, the Millennium Falcon, and so on. Most spin-networks correspond to a messy pile, rather than a model of anything. But combine spin-network parts the right way, and the result behaves (in a fuzzy quantum way) like a region of spacetime — just as the lego bricks can be put together as the Millennium Falcon. According to LQG, spacetime is put together in such a way.

The lesson to draw from this analogy is that space and time are not essential to the theory: instead LQG is a theory of elements that are not by themselves in space or time, but rather can combine in the right circumstances to make spacetime. (Similarly, there's no Millennium Falcon until the bricks are put together in the right way.) So if we want to talk about LQG in general, and not just in special cases, we cannot suppose that there is any space or time! (Where is everything if not in space? Does that even make sense? These questions are discussed in *Reality is Not What it Seems,* by Carlo Rovelli, one of the creators of LQG.)

'String theory' is our second example of a theory of quantum gravity. It describes the world in terms of 1-dimensional filaments, or 'strings', instead of the subatomic particles of high-energy physics — those of the Large Hadron Collider, for example. When quantized, the different ways that strings can vibrate correspond to the properties of different subatomic particles, and they are so short as to be indistinguishable from particles: so quantum strings explain the appearance of particles. Among the particles that appear in this way are 'gravitons', which in quantum mechanics 'carry' the force of gravity: two particles gravitationally attract when they exchange gravitons between themselves. (Equivalently, gravitons combine to make the curved geometry of spacetime.) Hence string theory is a theory of quantum gravity.

Strings have many interesting properties: quantum strings can split in two, or two strings can join to make a single string, or the two ends of a single string can join to make a loop of string; and the ends of strings can be fixed in space leaving the rest of the string to wiggle. And in a sense, strings don't care how big space is, or how it is knotted up — some say that as a result, space is not essential in string theory either. *The Elegant Universe*, by the string theorist Brian Greene, is a great starting point for these ideas. However, for now we only emphasize the difference between a 1-dimensional, extended string, and a dimensionless, unextended point particle.

Even these simple ideas are enough to see why, in three short examples, string theory and LQG raise questions for contemporary philosophy.

• Mereology:

'Mereology' is the study of how objects relate to their parts, and has been a pillar of metaphysics since before Socrates. An important aspect of mereology is whether or not an object can be broken down into ever smaller and smaller sub-parts, or whether there is a smallest element which itself has no parts. If some object can be broken down endlessly, we say that the object is 'gunky'*;* if the process of dividing reaches rock bottom, we say that this bedrock is a 'simple', something without parts. The question then is, is the world gunky or are there simples?

Recently, both philosophers and physicists have linked this question in mereology to string theory and LQG. Brian Greene argues that the strings of string theory are 'extended simples': they have no subparts and yet have length greater than nothing. According to *The Elegant Universe*, fundamental strings have no parts because that's what it is to be fundamental! Hence strings are "'atoms', uncuttable constituents, in the truest sense of the ancient Greeks" (p.141). However, one commonly supposes extended things, such as tables and chairs, to have parts and, therefore, not to be simples. Conversely, one commonly supposes that the only things without parts must be dimensionless points. If Greene is correct then the strings of string theory are exceedingly counterintuitive, and remarkably engage a two millennial old philosophical debate. The philosopher David Baker responds that while it might be true that strings are fundamental, it does not follow that they fail to have parts. In fact, string theory itself says that a string can split to produce two distinct strings. How can strings be simples, argues Baker, if they can be split into two? However, contrary to Baker, one could equally say that a string does not split, but is destroyed and two new strings are formed in its place. In this case, one need not infer that strings have parts. In any case, the debate over extended simples continues.

This debate can be recapitulated in the context of LQG, in which the geometry of the world is composed of lego-like bricks. There is thus a smallest unit, a partless brick, with a fixed (if fuzzy) volume (giving the impression of an fuzzily extended simple). However, unlike the strings of string theory, these bricks cannot be split into two.

Maybe Greene is right on these issues, or maybe Baker is — it's even possible that examples of extended simples can be found outside of quantum gravity. Our point is not to argue one way or the other, but to demonstrate that significant philosophical questions about the fundamental nature of reality are raised by developing physical theories today, just as in history; and that today's philosophers are trying to work out the answers just like their predecessors.

• Concrete and Abstract:

What is the difference between abstract objects, such as numbers, and concrete objects, such as protons, penguins, and planets? Consider the following two proposals. According to the first, proposed by Aristotle, something is concrete if it is located in space and time, and abstract if it is not. Call this the 'spacetime distinction'. Since the number 17 is not in spacetime, it is abstract; whereas penguins, which are in spacetime, are concrete. According to the second proposal, something is concrete if it can make changes to the world, and abstract if it is not. Call this the 'causal distinction'. Since 17 is just a number it does nothing, so it is abstract; whereas, since penguins cause changes to the world (catching fish for instance), they are concrete.

We can test whether criteria such as these are reliable by trying them out on clear examples of abstract and concrete objects to see if they get simple cases correct. For example, consider the (silly) claim that all concrete objects are made in literal concrete factories while anything not made in a concrete factory is abstract. This proposal works for objects like concrete cinderblocks, but (not surprisingly) fails when applied to penguins, which are concrete but not made of concrete.

Correspondingly, one of us has argued that both the spacetime and causal distinctions perform equally badly if LQG is true. As we have already seen, according to LQG spacetime is not a fundamental part of reality; but without spacetime, nothing can be concrete according to the first proposal since there is no spacetime for concrete objects to be in. Likewise, there is at root no time in which a causal process can take place; no causes producing later effects. So nothing can be concrete according to the second proposal either. But it seems that there should be some kind of abstract-concrete distinction to be drawn between the number 17, and a physical spin-network.

• Grounding:

Consider the statement “The stack of apples exists because of the apples that make it up.” It certainly seems true of the apples in my kitchen, but how should we understand the “because”? How exactly does the stack depend on the apples? Do the apples *cause* the stack to be, perhaps? No, my going to the store, bringing apples home, and stacking them caused the stack, not the apples. Philosophers sometimes say that instead of being caused by the apples, the stack is ‘grounded’ in them. Generally, there seem to be two ways that one thing can depend on another: either one causes the other, or if not it is grounded in it. Call this the ‘causal criterion’ of grounding: depending without causing.

In many cases, this criterion seems to work quite well. Consider the following two facts: (a) my window broke because the children's baseball hit it, and (b) my window broke because it was fragile. The form of these statements are similar, though they express very different things. (a) describes a relation between events, while (b) describes a relation between properties of my window (its fragility and its brokenness). In (a) the dependence expresses a casual process in time: at one time the window was intact, then the baseball hit it, causing it to break. On the other hand, it seems odd to say that being fragile caused my window to break, thus according to the causal criterion the window being broken is *grounded* in its fragility.

Metaphysician Alastair Wilson argues, however, that the causal criterion (and many others) would fail if LQG were true. The argument is straight-forward. As we already discussed, without time there are no causal processes at all, so the criterion does not distinguish cases like (a) from those like (b). The only way for one thing to depend on another is by being grounded by it. However, theorists of LQG still make dependence claims, particularly that space and its geometry depend on spin-networks. Just how is a difficult question, but we don’t want to prejudge that it couldn't be causal in some sense.

Given that the causal criterion fails, Wilson proposes a new criterion, which he argues works for spin-networks (as well as for windows). According to this criterion, a dependence relation is causal if it involves physical laws. Wilson then argues that since LQG is a physical theory, it must postulate some law-like principles or restrictions on what the physical world is like. If Wilson is correct, then even though there is no time in LQG, there are laws, and because there are laws, his criterion is applicable. And if spacetime and spin-networks are suitably related by physical laws, then spin-networks might cause spacetime rather than ground it: it depends on the details of their relationship.

These three examples of ongoing debates have been chosen because they illustrate well how physics bears on traditional philosophical questions. They show how quantum gravity has the potential to challenge our most basic conceptions of reality. Of course, the radical idea that space or time are not fundamental challenges many other deep philosophical assumptions about the world. While we cannot investigate them further here, many are discussed in a series of video lectures from the *Space and Time After Quantum Gravity* project (see *Works Cited*).

3. The dance of physics and philosophy

Our historical examples show how the process of creating new physical theories spurs philosophical investigations. As the classical mechanics of Descartes, Newton, and Leibniz was developed, it threw up conceptual puzzles and questions: what are the fundamental ingredients of physical reality, and what can we know of them? What place does God have in the new world being discovered? The examples drawn from contemporary philosophy show the very same thing about today's developing physics. (More examples can be found in Tim Maudlin's *The Metaphysics Within Physics,* for instance.)

Although some of the historical issues may seem irrelevant or settled today, they were some of the most important issues of their time: Descartes was perhaps the most famous philosopher of his age, and the Leibniz-Clarke Correspondence was widely read. But what is it about physics (or other sciences) and about philosophy that makes one so important for the other?

Most philosophers today would agree that although philosophy is less directly answerable to experience than physics, it still has hidden physical, empirical assumptions and consequences. In our historical examples, views on the nature of God, space, time, matter, and so on turned out to depend on the nature of the physical world, as revealed through experiment and observation. And it's not surprising that such discoveries would be philosophically important, since they bring new, empirical considerations into philosophy, fundamentally changing our understanding of the issues.

It is our contention that the very same can be said of the insights that the developing science of quantum gravity offers philosophy: for instance regarding mereology, the nature of abstract objects, and grounding.

Still, one might wonder why philosophy should be concerned with today's incomplete proposals for quantum gravity. Wouldn't it make more sense to wait until the correct physics is discovered? But the question presupposes a faulty picture of science. The discovery of new physics is not an instantaneous event, but a process, taking decades or more in our examples. Correspondingly, the impact on philosophy did not occur *after* a new theory was accepted, but *during* its development: the issues did not wait, but were part of the process. Why should this be?

It may have already struck you that the protagonists in our examples were not only engaging in philosophical debate, they were also some of the very people involved in the process of developing classical physics: especially Descartes, Newton, and Leibniz. That is because their philosophical inquiries were inseparable from their physical ones. They understood that what was needed was not simply new laws, but a new conceptual framework for physics. In part, a new framework for knowledge was needed: one thread through Descartes and Newton is understanding the contributions of rational thought and experiment to knowledge. In part, the place for God had to be rethought: ultimately, appeals to God's nature became illicit in scientific argument. Similarly, the nature of causation was rethought and contested: once Aristotle's powers are abolished from science, do things act only locally, or at a distance?

The general point is that physics has very general presuppositions, some explicit, some hidden. These concern good methods, the appropriate concepts to use, and the principles governing good scientific explanation (and more). Sometimes they need to be revised to make progress, but such revision is not simply a matter of hypothesis and experiment. Instead assumptions must be unpacked and critiqued, and new foundations found. In other words, it requires the kind of conceptual reflection that goes under the heading of 'philosophy'.

That is a very sweeping claim, and plays out differently in different cases (and does not apply to every episode in the history of physics): the philosopher Michael Friedman makes a strong case for it in *The Dynamics of Reason*, which inspires this discussion. But now we can see why philosophical reflection occurs during the development of new science, not just after – *because it is part of that development*. And of course we propose that philosophical investigation of quantum gravity can play a similar role in its development today. (Though we do not say that every philosophical question raised will turn out to be significant in that development!)

Some may object to a role for philosophy in physics. But we have given examples of philosophical presuppositions and the debates surrounding them. Some may accept that there are philosophical presuppositions, but suggest that philosophy is no longer needed because we have the right ones. But people have thought that before, and been proven wrong: it is hubris to think that we have reached the end of such discoveries.

Some might object that the historical examples do not show our point because they involve physicists, and therefore involve physics not philosophy! But the examples refute this distinction. Another way of making our point is to say that physics is not distinct from philosophy; instead, there is a part of physics which *is* philosophy. Thinking about things this way requires thinking about philosophy as a kind of activity to be found in many places, not just a philosophy department. The physicists we discussed were engaged in this activity as part of their physical discovery. And in fact, physicists still debate philosophical issues, even if they don't always describe their debates as philosophical.

Some may be concerned that if physics involves philosophy then it comes adrift from the kind of assurance that experiment can provide: how will we tell what's right if we are relying on philosophical analysis? That's a legitimate concern, and indeed a contentious one. For now, we will make the following points of reassurance. First, philosophy itself does have rules: logic, and careful analysis of meaning and use, for instance. Second, any progress in physics is progress towards solving some concrete problem, with concrete physical applications: predicting and explaining specific observations and experiments, ultimately building machines and harnessing nature. The philosophy that we have been discussing helps discover the intellectual tools needed to solve such a problem, but whether the resulting theory can be successfully applied as intended is not subjective.

We started this essay with the question of how physics can inform philosophy; a question that we answered with historical and contemporary examples, which helped to show that philosophy has physical, and empirical assumptions, even if they are often well-hidden. But we noticed that philosophy responds to physics as it develops, not just after the dust settles, and wondered why. Answering this question closed the circle: philosophy informs physics, because physics makes philosophical assumptions, which must sometimes be revised by philosophical analysis in order to make progress. In this way, physics and philosophy are not polar opposites as the original question supposed, but overlapping enterprises, joined in a never-ending dance.

Works Cited

1. Clarke, S., Leibniz, G., and Newton, I. (1956). *The Leibniz-Clarke correspondence: together with extracts from Newton's Principia and Opticks.* Alexander H. (ed.). Manchester University Press.
2. Descartes, R. (1986). *Meditations on first philosophy: with selections from the Objections and Replies*. Cottingham, J. (ed.). Cambridge University Press.
3. Descartes, R. (1983). *Principles of Philosophy*. Miller, V.R., and Miller, R. (trans.). D. Reidel Publishing Company.
4. Friedman, M. (2001). *The Dynamics of Reason.* CSLI Publications.
5. Greene, B. (1999). *The Elegant Universe.* Vintage Books. W. W. Norton & Company.
6. Kuhn, T. (1957). *The Copernican Revolution*. Harvard University Press.
7. Maudlin, T. (2007). *The Metaphysics Within Physics.* Oxford University Press.
8. Newton, I. (1999). *The Principia: mathematical principles of natural philosophy.* Cohen, B., Whitman, A. University of California Press.

9. Rovelli, C. (2016). *Reality is Not What it Seems: The Elusive Structure of the Universe and the Journey to Quantum Gravity.* Penguin Books.

10. Smolin, L. (2001). *Three roads to quantum gravity*. Basic Books.

The videos discussed (and a presentation of this essay) can be found at: https://www.youtube.com/c/BeyondspacetimeNet.

Friday, September 7, 2018

Contact: huggett@uic.edu