There really is no such thing as Science. There are only scientists

The question how science could be different touches on almost the entire history of human culture.[1] In this respect (and many others!) science is very similar to art. Gombrich's famous book *The Story of Art* from 1950, from which my title has been adapted, saw 'the great awakening' of art in ancient Greece and thence took an almost entirely Western perspective (incidentally not mentioning a single female artist). But he was right in emphasizing the idea that art is a purely human endeavor that emerged from specific cultural settings, even at the time when it was still "figurative".

And so did natural science and mathematics, even when the latter was still supposed to describe the real world (which arguably ceased to be the case only in the 19th century).[2] Here, too, traditional historiography starts from the Greeks and then takes the story to Western Europe, typically followed by a turn to the U.S.A after 1945.[3] This historiography is currently being challenged by projects like the decolonization of the syllabus,[4] and in a different way the feminist philosophy of science,[5] both of which emphasize that prior concepts of the nature of knowledge as well as prevailing social norms influence not just the interpretation and use of data and knowledge, but even what we call data and knowledge. At the very least, this yields an indubitable path-dependence of science and even mathematics, but more radically, it might be the case that there simply is no such a thing as natural science in the sense of an objective and uncontroversial description of nature. In that case, the tension between the alleged objectivity of the things to be discovered and the subjectivity of the human explorers and their cultural settings simply cannot be overcome, as famously expressed by Eddington:

'*We have found a strange foot-print on the shores of the unknown. We have devised profound theories, one after the other, to account it origin. At last, we have succeeded in reconstructing the creature that made the foot-print. An Lo! It is our own*.[6]

Since the all-encompassing nature of the question makes a comprehensive coverage impossible in any (finite) number of pages, let alone nine, I will restrict myself to an analysis of the interaction between mathematics and physics, and even within this limited context I will only sketch alternative pathways that are based on early Chinese science and philosophy, or on African philosophy. But there are good reasons for these restrictions. First, mathematical physics was both a trigger and a high point of the (alleged) scientific revolution in the 16th and 17th centuries, culminating in the work of Newton. Second, ancient Chinese science is well documented in translation,[7] whilst African philosophy is increasingly being (re)discovered and appreciated.[8] The main point, however, is that both fundamentally differ from the Greek paradigm, which especially through comparisons like this loses its status as the unique source of rationality and rather comes out as just one of the possibilities among various others.

Summarizing a widely accepted picture of the history of science,[9] the main points are:

- Arguably the main innovation of ancient Greek philosophy was the separation of the natural from the supernatural, realizing that nature was governed by regularities, mechanisms, cause and effect, etc., rather than by magic and divine intervention.
- In the fifth century BCE, the earliest Greek natural philosophers such as Leucippus and his student Democritus, followed by e.g. Epicurus around 300 BCE, developed the idea of atomism, according to which small invisible bodies and their interactions account for the entire structure of the world, free of divine intervention. Perhaps the most striking—and modern—aspect of ancient atomism is the idea that the world is not what it appears to be, in other words, that the nature of reality is hidden.
- From the fifth century BCE onwards, lasting a few centuries, due to the political structure of their city-states (especially Athens) Greek citizens were exceptionally well trained in adversarial debate, practicing this art in law courts, in decision-making assemblies, and on the market square (*Agora*). This included the evaluation of evidence, logical argument, accountability, and aiming at ultimate justification.
- Within this polemic debating culture, Socrates and his pupil Plato (and probably others) were annoyed by sophisms and tried to improve the level of debate by adding clarity and precision through the use of unambiguous *definitions* (which they never found), standards of *proof* (which were only formalized in the 20th century by Hilbert), and a general aim of finding the truth (as opposed to winning a debate or lawsuit). This came with a taste for abstraction and generalization, and more generally for theorizing for its own sake. In this setting, mathematics flourished (or some say: was invented) and reached its axiomatic-deductive (i.e. definition-theorem-proof) format used in Euclid (300 BCE), and ever since. Definitions are *sharp*, and mathematical statements ("sentences") are either *true* or *false*.
- Perhaps following the legendary Pythagoreans (and, as we now know, the Neo-Babylonian astronomers), Plato surmised that the Cosmos had a mathematical structure, based (at least in the *Timaeus*) on geometry and on harmonics.
- Aristotle pioneered biology and physics, based on observation and a search for "essences". Although mathematics had been applied to astronomy (and astrology!) at least since Babylonian times, Aristotle did not advocate its use in physics, arguing that mathematics was man-made and concerned with unchangeable objects, whereas physics was independent of man and concerned with change—this was part of his strict classification and division of the "demonstrable sciences".[10] Aristotle did not endorse atomism either. Hence what we call science was both created by his precise and systematic methods, including classification, logic, definition, and proof, and held back for 2000 years by the particular negative attitudes just mentioned.[11]

- On the other hand, for my main theme it is interesting to quote Morris Kline here concerning other causes of this delay, which may account for at least half of it:[12]

‘The Roman civilization was unproductive in mathematics because it was too much concerned with practical and immediately applicable results. The civilization of medieval Europe was unproductive in mathematics for exactly the opposite reason. It was not at all concerned with the physical world. Mundane matters and problems were unimportant. Christianity put its emphasis on life after death and on preparation for that life. Apparently mathematics cannot flourish in either an earthbound or a heavenbound civilization. It has been most successful in a free intellectual atmosphere which couples an interest in problems presented by the physical world with a willingness to think about ideas suggested by these problems in an abstract form that makes no promise of immediate or practical return. Nature is the matrix from which ideas are born. The ideas must then be studied for themselves. Then, paradoxically, a new insight into nature, a richer, broader, more powerful understanding, is achieved, which in turn generates deeper mathematical activities.’

- Various authors differ about the key ingredients of the scientific revolution (some even deny there ever was such a thing), as well as about their relative weight, but few would deny that *the mathematization of nature* and the introduction of *experiments* in natural science were decisive, especially in combination with each other, as in the work of Galilei. The former in turn had its intellectual origins in the rediscovery of Plato, as well as more practically in perspective painting, double-entry accounting, cartography, navigation, ballistics, fortification, etc. Thus Aristotelian essences were effectively removed from natural philosophy and were replaced by mathematical descriptions. Experiments as such were less novel, as shown by the example of Alhazen in optics, or by alchemy, but before the 17th century scientific experimentation was far from widespread and systematic. In addition, better *observations* played a crucial role, both with the naked eye (Brahe) and via new technologies (like telescope and microscope). All of this culminated in the work of Newton, who shaped modern science by injecting the new combination of mathematics, experiments, and superior observation into the old natural philosophy.

Could it have been different? One need not be a Marxist to recognize that the political circumstances in ancient Greece played an important role, especially in the creation of mathematics and Socrates-style philosophy based on the search for definitions. These circumstances were very different in ancient *China* (at around the same time), to which indeed almost none of the above characteristics apply. First, a strong central ruler supposedly received his mandate from Heaven, which made state, cosmos, and nature practically inseparable. The Greek doctrine of atomism was replaced by the idea of a fundamental substance called *qi*, arguably more a process than a form of matter, subject to *yin* and *yang*, which originally referred to the sunny and the shady sides of a mountain, but were later abstracted as opposing forces that needed to be balanced.

Neither *yin* nor *yang* should ever win: the aim of the ruler and his advisors was to achieve harmony in the state, in nature, as well as in man, by finding the right balance. Note that these advisors (i.e. civil servants) included the “thinkers” of the time, who enjoyed a much higher social status than contemporary Greek philosophers (except perhaps for the wealthy aristocrat Plato) and hence personally had much to lose from instability. Thus a crucial difference with ancient Greece and its polemic debating culture was the aim of harmony, whilst recognizing the existence of opposing sides. But one should not choose between these, as in “true” or “false”, as the Greeks did, but balance them. This typically Chinese idea of a balancing act between contradictory forces and views reached well into the 20th century, as shown for example by “Mao Zedong Thought”. The effective inseparability of nature from man and the state also showed through the ancient idea of the *five agents* (also called *phases*), which might be wood, fire, earth, metal, and water, but could equally well refer to birth, growth, maturity, decay, and death, or to benevolence, righteousness, propriety, judgement, and sagacity, *etc*.

These ideas by no means stood in the way of flourishing technology and mathematics. In the first sector the Chinese were arguably ahead of Europe (Needham), and in the second the anonymous *Nine Chapters on the Mathematical Art* from the second century BCE is on a par with Euclid. Although the style is not axiomatic-deductive, or theorem-proof based, the famous commentary by Liu Hiu from 263 CE includes explanations and what we would now call verifications of the algorithms contained in the *Nine Chapters* that play the role of proofs. One difference surely lies in its more practical orientation, which even includes techniques for the simultaneous solution of three linear equations.

With hindsight, the Greeks and the Chinese both got their mathematics right, but the former emphasized proof whilst the latter focused on algorithms and computation. Neither had the concept of a symbolic mathematical equation or formula, which was an early modern invention (usually credited to Viète and Descartes). Greek atomism was on the right track, although I will later argue that a different kind of physics might be possible. Aristotle introduced something like a systematic scientific method, which however excluded mathematics and experiment, both of which are keys to modern science and which in my view are indeed indispensable. His physics was also wrong. Yet the totality of the Platonic-Aristotelian corpus played an essential role in triggering the scientific revolution, if only by rediscovering Plato and rejecting Aristotle. It would be incorrect to say that Chinese physics was equally wrong, for in the lack of a separation between nature and man, arguably there was no such a thing as Chinese physics. As we will see, the paramount idea of harmony might have led to an alternative science.

I now turn to *African philosophy*. This is rarely if ever considered in the context of the history of science, on whose development it probably had no influence, but we shall see that it contains ideas that are strikingly different from the mainstream Western thought that did lead to modern science, and as such it suggests interesting divergences.

Some authors refer to African philosophy as a 20th-century phenomenon that arose in reaction to centuries of slavery, colonialism, and racism. Others start from a legendary contemporary of Socrates called Orunmila from Ife (Nigeria), who apparently played a similar founding role (though his name is difficult to find even in specialized monographs and websites).[13] In the oral transmission of Orunmila's ideas one sees recurrent themes that are opposite to those of Socrates and Plato. One is the important role of experience (which Plato saw as misleading), continuing into the modern era as a strong empiricism. Another is the relative nature of ethics (instead of a search for the absolute good), and in its wake perhaps not so much the aim of *reconciling* opposites, as in Chinese philosophy, but of denying that for example good and evil *are* opposities in the first place. Likewise, the natural and the supernatural are not opposed to each other, let alone mutually exclusive. This non-duality equally well makes it unnecessary to choose between opposites, as in the binary world picture of the Greeks—one sometimes reads that African philosophy is based on the *inclusive* "or" whereas Western philosophy is based on the *exclusive* "or" (though ironically, Western logic is based on the former!). Similarly, Idea and Matter are seen as complementary and inseparable (instead of one being subordinate to the other, as in much of Western philosophy).

Even 2500 years later, the theory of truth defended by one of Africa's leading contemporary philosophers, Kwasi Wiredu (1931-2022) is strikingly in the same spirit: truth is not objective but is always *someone's* truth, seen as considered opinion (Wiredu's argument against absolute truth is essentially that it would be unknowable of it existed).[14] Unfairly comparing African theology or even folk wisdom with Western science, reflecting on the role of God(s), ancestors, spirits, magic, and witchcraft in African thought led the early French and English anthropologists to derision or at best to claims of the irrational or pre-scientific nature of African thought. But in fact this gives interesting information about the role of forces and causality in African philosophy. For example, African thought has always been open to *invisible* forces (such as interaction —via rituals— between immortals such as ancestors and mortals),[15] in a way that perhaps resembles Newtonian gravity via action at a distance, as opposed to the mechanical contact forces on which cartesian physics was based. One of the first European students of African philosophy, the Flemish missionary Placide Tempels (1906-1977), argued that the key difference between Buntu and Western philosophy was the idea that in the former "force" between objects is the starting point, the objects being secondary, whereas in the latter the opposite prevails: objects first, force second. This is compatible with the *Ubuntu* principle "*I am because we are*", expressing the idea that man is not primarily an individual but a member of a community. These days Western academics tend to learn this in leadership and management courses!

In conclusion, African philosophy provides an interesting and coherent body of ideas, only very superficially summarized above, which in being primarily participatory is clearly different from the primarily individualistic and objectivist Western philosophy.

Summing up, what was decisive in the Greek achievement as a pathway to modern science was the separation of the natural from the supernatural. Furthermore, the ancient Greeks contributed atomism, the speculation that the cosmos ultimately had a mathematical structure, the invention of axiomatic-deductive (or definition-theorem-proof based) mathematics, and an altogether systematic approach probably going back to Aristotle. Both atomism and Plato's mathematical cosmos contributed to the insight that there is a deeper layer of reality behind the appearances, having ample explanatory force. On the down side, there was far too much armchair speculation, no serious experimentation (except perhaps in Aristotle's biology), and mathematics was not applied to natural philosophy (which was separated from the so-called middle sciences — later called *mixed mathematics*—viz. astronomy, harmonics, and optics, which were based on mathematics even at the time). The winning combination of natural philosophy with both systematic experimentation and mathematics had to wait for 2000 years.

The first step seems absent in both ancient Chinese and African philosophy. Atomism seems anathema to both; individuation did not come naturally and was replaced by process-based concepts like *qi* and (vital) force. More generally, interactions by themselves seemed more important than the objects mediating them. The Chinese possessed advanced forms of mathematics and astronomy and did make the link between the two, though the link with the state and the emperor ("*Son of Heaven*") was never lost. There is no record of any African mathematics comparable to Euclid or the *Nine Chapters* (although for example the Dogon tribe in Mali made advanced astronomical observations well before colonization). Unlike the observation-based Chinese sciences, African philosophy was wide open to invisible structures having reality and explanatory power. Systematic experimentation was surely present in Chinese technology, which until the modern era was well ahead of European (and African) technology, as far as I know it did not contribute to the development of science as it would do in Europe during the scientific revolution. Last but not least, the emphatic opposition between "right" and "wrong" in ancient Greek thought, from ethics to mathematics, had no counterpart in China and Africa: *yin* and *yang* are admittedly opposites but they have to be reconciled or harmonized, whereas the very notion of mutually exclusive opposites seems alien to traditional African philosophical thought.

There are two ways to proceed on the basis of an analysis like this. First, one could discuss the counterfactual question what would have happened to the history of science if Chinese or African (or indeed any other relevant non-European) ideas had been more influential (Islam being well documented). This is a problem in *causal inference*. In simple problems of this kind (such as the causal effect of medication) one performs a *randomized trial*, which obviously makes no sense here. Otherwise, one performs what in (micro) economics is called a *natural experiment* (a classical though sad example is the influence of the death penalty on the homicide rate in the U.S., where a refined temporized comparison with the situation in Canada showed it had no effect).[16]

In the case at hand, one should try to find a situation where something like European science *was* in fact influenced in the said way, or, alternatively, China or Africa underwent certain developments like the ones that in Europe led to modern science Unfortunately, this type of experiment seems impossible for the history of science, so that one is left with idle speculation (or even wrong conclusions, like the old idea that the death penalty decreases manslaughter, which was refuted by a natural experiment).

Thus we are left with the second option, which studies the possible effect on modern science by taking appropriate Chinese and/or African ideas into account. As already mentioned, I concentrate on mathematical physics, and arrive at two conclusions:

- "European" *mathematics* is unexpectedly flexible. Although the Greek opposition between "right" and "wrong" has deeply penetrated into set theory and first-order logic (i.e. two sets are equal or they aren't; a set contains another set as an element or it doesn't; a sentence is true in some interpretation or it isn't; and, after Gödel, a true sentence is provable or it isn't), non-classical logics (as well as both Brouwerian and Gödelian undecidability) can be described *within* the ensuing "binary" formalism of modern mathematics. So even if opposites are classically incompatible or at least stand in an uneasy relationship, this can be accommodated. And indeed this has been done in various ways, for example in quantum theory, where various new logics as well as Bohr's notion of complementarity have been described *within* the confines of "classical" set-theory based mathematics without any problem.[17] In fact, Niels Bohr, who only used elementary (and hence classical) mathematics, famously had the *yin* and *yang* symbols on his coat of arms. John von Neumann was one of the founders of both classical set theory and quantum logic. Modal logic is another case in point.

- "European" *physics*, on the other hand, could be set up in a genuinely different way that does justice to the uneasiness with individuation in both African and Chinese thought, with its accompanying emphasis on relations. Looking at the three great frameworks of modern physics, namely (in order of appearance) statistical mechanics, general relativity, and quantum (field) theory, the influence of atomism on the first and the last is paramount. In all its procedures, from determining the degrees of freedom to defining a Hamiltonian to computing partition functions etc., statistical mechanics *starts* from atoms or molecules and *then* adds interactions. The fact that the latter can be done at all gives modern physics a flexibility akin to that of modern mathematics, but nonetheless, individuation comes first and relations or forces come second.

  Similarly, quantum mechanics started as a theory of atoms and light and developed into quantum field theory, which, like statistical mechanics, both in its inception as quantum electrodynamics and also in its principal experimentally verified version as the language of the Standard Model of high-energy physics is a theory of (elementary) particles *first* and their interactions *second*. This is especially clear in collider physics, where the asymptotic states that are actually detected are theoretically treated as non-interacting particles on their mass shell, whose earlier interactions are described by perturbation theory via Feynman diagrams. Indeed, even without claiming that quarks etc. are “constructed”,[18] a case could be made that the collider experiments whose cross-fertilization with the ups and downs of quantum field theory (QFT) led to the Standard Model were based on the kind of atomic imagery that started with the Greeks, was taken up by Newton, and has dominated physics since Boltzmann. Similarly, an important goal of QFT in condensed matter physics is the identification of quasi-particles (like valence electrons or phonons or plasmons) that move (almost) freely through the material in question and determine its properties.

General relativity, on the other hand, is not based on particles and is precisely the theory at odds with quantum (field) theory. Though also the scientific study of gravity and motion on which general relativity is based is decidedly “European” in its history (as is the mathematics underlying general relativity), Einstein’s theory is not in any way atomistic in spirit. Instead, certainly historically, through his reliance on Mach’s principle in finding the theory Einstein had a mindset that might rather be called holistic—even the very word “relativity” concerns the behavior of bodies *with respect to each other*.

If, therefore, some non-European ideas of the kind described could fuel the resolution of the clash between general relativity and quantum (field) theory—often seen as the “holy grail” of theoretical physics—it would most likely be quantum theory that needs to be reformed. On the side of *interpretations* of quantum mechanics, various “non-European” ideas have already been proposed from the start, beginning with Bohr’s idea of complementarity and his later holistic concept of a *phenomenon*, continuing with Everett, and more recently including modal and relational interpretations. It therefore seems that the formalism itself needs a side kick. In particular, the above analysis suggests that quantum field theory should be stripped of its reliance on individuation. This refers not only to particles, but even to fields, since these are typically introduced as the primary (“individuated”) degrees of freedom, *after which* interactions are added. Moreover, in the perturbative (Feynman diagram) picture, these interactions are themselves carried by particles (viz. photons and other gauge bosons)! But even what is called non-perturbative quantum field theory, which is not based on particles and Feynman diagrams, is still off track, starting as it does by first individuating fields.

Doing quantum field theory without fields is like doing differential geometry without coordinates. Indeed, progress in general relativity after Einstein, such as the singularity theorems of Penrose and Hawking, rely on global (topological) concepts and would be unthinkable in coordinates—which reconfirms the fact that general relativity was already on the right track, at least from the point of view expressed in this essay. So a similar step needs to be taken on the QFT side. I expect this to be a key step forward in fundamental (mathematical) physics and have some ideas on how to accomplish it. This is not the right place to enter into details, except to say that the aim of introducing Chinese and especially African ideas played a signifiant role in arriving at these ideas.

Irrespective of any concrete proposals, my suggestion that the incorporation of non-Western ideas that are critical of individuation points at quantum theory as the culprit may hopefully stand on its own and gives a hint how exactly science could be different.

[1] Earlier approaches typically study the issue as a problem in the philosophy of science related to (anti-) realism, see e.g. L. Soler, E. Trizio, and A. Pickering (eds.), *Science as it Could Have Been: Discussing the Contingency/Inevitability Problem* (University of Pittsburgh Press, 2015).

[2] [2] See for example J. Grey, *Plato's Ghost: The Modernist Transformation of Mathematics* (Princeton University Press, 2008).

[3] Traditional historiography of natural science and mathematics is represented by, for example, the otherwise brilliant books *The Mechanization of the World Picture* by E.J. Dijksterhuis (Oxford University Press, 1961, Dutch original from 1950) and *Mathematical Thought from Ancient to Modern Times* by Morris Kline (Oxford University Press, 1972), respectively.

[4] With hindsight, in the history of mathematics this started already with the *Geschichte der Mathematik im Mittelalter* by A.P. Juschkewitsch (Pfalz-Verlag, 1963, Russian original from 1961). See also *The Crest of the Peacock: Non-European Roots of Mathematics* by G.G. Joseph (Penguin Books, 1991) and D. Hermann, *Mathematik im Mittelalter: Die Geschichte der Mathematik des Abendlands mit ihren Quellen in China, Indien und im Islam* (Springer, 2016).

[5] See e.g. M.C. Amoretti and N. Vassallo (eds.), *Meta-Philosophical Reflection on Feminist Philosophies of Science* (Springer, 2016), especially Chapter 2: M. Harrell, On the possibility of feminist philosophy of physics, also at https://philpapers.org/archive/HAROTP-15.pdf.

[6] A.S. Eddington, *Space, Time, and Gravitation* (Cambridge University Press, 1920), p. 201.

[7] This started with J. Needham's book series *Science and Civilisation in China,* published by Cambridge University Press from 1954 till and beyond his death in 1995. More recent books include G.E.R. Lloyd and N. Sivin, *The Way and the Word: Science and Medicine in Early China and Greece* (Yale University Press, 2002), and R. Littlejohn, Chinese Philosophy and Philosophers: An Introduction, 2nd ed. (Bloomsbury, 2022), conveniently summarized by Littlejohn's *Internet Encyclopedia of Philosophy* entries such as https://iep.utm.edu/chinese-philosophy-overview-of-topics/. I am unfortunately unable to read Chinese.

[8] One of the first appreciations of African philosophy, still worth reading, was P. Tempels, *Bantoe-Filosofie* (Kongo-Overzee Bibliotheek, 1946), by a Flemish missionary convinced of the superiority of Christian "civilization". French and English translations (as well as the Dutch original) are available at http://www.aequatoria.be/tempels/. An early work by an African author is *The Mind of Africa* by W.E. Abraham (Univ. of Chicago Press, 1962). For surveys see e.g. B. Hallen, *A Short History of African Philosophy* (Indiana Univ. Press, 2002), P.H. Coetzee and A.P.J. Roux (eds.), *The African Philosophy Reader, Second edition* (Routledge, 2003), K. Wiredu (ed.), *A Companion to African Philosophy* (Blackwell, 2004), and L.T. Outlaw Jr. and J. Chike, Africana Philosophy, T*he Stanford Encyclopedia of Philosophy* (Fall 2022 Edition), E.N. Zalta and U. Nodelman (eds.), https://plato.stanford.edu/archives/fall2022/entries/africana/.

[9] S. Gaukroger, *The Emergence of a Scientific Culture: Science and the Shaping of Modernity 1210-1685* (Oxford University Press, 2006); E. Grant, *A History of Natural Philosophy: From the Ancient World to the Nineteenth Century* (Cambridge University Press, 2007); D.C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, Prehistory to A.D. 1450* (Chicago University Press, 2007); H.F. Cohen, *The Rise of Modern Science Explained: A Comparative History* (Cambridge University Press, 2015); D. Wootton, *The Invention of Science: A New History of the Scientific Revolution* (Allen Lane, 2015); D. Levitin, *The Kingdom of Darkness: Bayle, Newton, and the Emancipation of the European Mind from Philosophy* (Cambridge University Press, 2022).

[10] See for example *Physics*, 192b9—195b30, for a summary of Aristotle's views on this. Recent literature includes L. Judson, *Archiv für Geschichte der Philosophie* 101, 177-204 (2019) and P.M. Distelzweig, *Apeiron* 46, 85-105 (2011). The situation is of course more subtle than my main text suggests!

[11] To Aristotle's credit, the inherent tension in mathematical physics that he pointed out remains: how can the objective physical world be captured by a man-made language?

[12] M. Kline, *Mathematical Thought from Ancient to Modern Times* (*loc. cit*.), pp. 204-205.

[13] The only source seems S. Bosede Oluwole, Socrates and Orunmila: Two Patron Saints of Classical Philosophy (Ark Publishers, 2015).

[14] A good starting point is S. Osgha, *Kwasi Wiredu,* https://iep.utm.edu/wiredu/.

[15] Cf. e.g. L.J. Teffo and A.P.J. Roux, Metaphysical thinking in Africa, *The African Philosophy Reader,* eds. P.H. Coetzee and A.P.J. Roux, pp. 134-148 (Psychology Press, 1998).

[16] Half of the 2021 Nobel Prize for Economics to Angrist and Imbens was awarded for this kind of causal inference. A good review is J.D. Angrist and J.S. Pischke, *Journal of Economic Perspectives* 24, 3-20 (2010). See also G.W. Imbens and D.B. Rubin, *Causal Inference for Statistical, Social, and Biomedical Sciences* (Cambridge Univ. Press, 2015).

[17] See for example K. Landsman, *Foundations of Quantum Theory* (Springer, 2017).

[18] As in A. Pickering, *Constructing Quarks: A Sociological History of Particle Physics* (Univ. of Chicago Press, 1984), whose provocative title perhaps masks its impressive scholarship.