SEEK FUNDAMENTALITY, AND DISTRUST IT[1]

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"[F]undamental progress has to do with the reinterpretation of basic ideas."
Alfred North WHITEHEAD (1948, pp. 227–228)

Ideas and opinions about what is fundamental give direction to entire research programs in physics. By bringing the implicit assumptions about fundamentality into focus, this essay checks whether a reinterpretation is in order.

1. Getting at the roots

Language is an old fortress, in which analogies and metaphors have entrenched hidden doors and secret passageways. They make us tumble from one meaning into the next, like Alice down the rabbit hole. If we want to see things for what they really are, we must escape the intricate poetry of our language. So, let us start at the beginning, by investigating the etymology of 'fundamental'.

Luckily for us, the metaphor in the word 'fundamental' is easy enough to identify, especially with the help of the Oxford English Dictionary. It stems from the post-classical Latin *fundamentalis*: "of or relating to the foundation or base (4th or 5th cent. in Augustine)". This literal, solid basis of a building is used symbolically for something that provides a stable ground.[2] Bottom positions are intuitively associated with stability for us, creatures who dwell on the surface of a gravitationally non-negligible planet. And our experience with the permanence of concrete foundations only adds to the gravity of the metaphorical sense of the term. These associations do come with some drawbacks, as we'll see next.

1.1 Two projects of natural philosophy

Since a building has only one foundation, the metaphor may hamper pluralism. In addition, the metaphor suggests that the referent ought to be as concrete as possible. Yet, starting with the natural philosophers, the project of physics has always encompassed at least two projects for foundations:

(1) the search for **concrete 'elements'**, which has evolved from earth, water, air, and fire (and aether) to the particle zoo of modern physics; and

(2) the search for **abstract principles** (*archai*), which must be simple enough for humans to understand. This second project is close to mathematics and looks for laws of nature and universal equations, from which many phenomena can be derived.

Project (1) assumes that there exist fundamental things in the world, independent of our knowledge thereof – philosophers call this an 'ontological' claim. Project (2) only requires us to identify fundamental parts of our knowledge - merely making an 'epistemological' claim.

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[1] The title of this essay is a variation on what ought to be the "guiding motto in the life of every natural philosopher" according to WHITEHEAD (1920, p. 143): "Seek simplicity, and distrust it".

[2] Notice that both ground and solid are entrenched metaphors, too. Once you start looking for metaphors, you'll find our language bristling with them – like a seemingly still drop of pond water that is full of life.

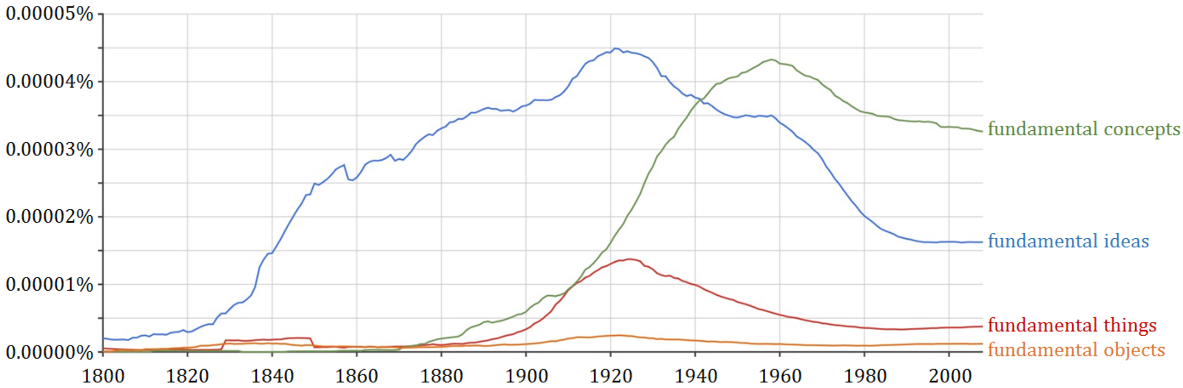

Figure 1: Graph comparing the percentage of Google Books in the 1800–2008 English corpus containing the phrases "fundamental concepts" (green), "fundamental ideas" (blue), "fundamental things" (red), and "fundamental objects" (orange) (smoothed over decades).

In general usage, 'fundamental' also occurs in both senses: **Fig. 1** illustrates that it is mostly used for abstract referents (such as concept and ideas), but not exclusively (since things and objects occur to). In philosophy, we are not primarily interested in how people happen to use concepts, but in how we should think about them, ideally.

Hence, a crucial question in this essay is: should physicists look for what is fundamental in the physical world? Should they reserve the term for their theories? Or can they keep using it for both? I shall argue for the second option: it seems wiser to reserve the adjective 'fundamental' to abstract, formal and mathematical entities.

1.2 Partless parts

An important connotation of fundamentality is that of simplicity, both in the sense of (1) not being composite and (2) being immediately clear. Both senses are connected: when something is immediately clear, we don't require separate steps in our reasoning. For our current purposes, however, it seems crucial not to conflate them. Whereas the first sense may refer to concrete things in the physical world, the second one applies to theoretical notions only, such as ideas, theorems or proofs – mirroring the two projects of natural philosophy.

Both in the context of mathematics and physics, there is an historically important project to look for parts that are themselves without parts. In Euclidean mathematics, we find it as 'points' and, in the physical sciences, we find it as 'atoms', 'elements', and 'elementary' or 'fundamental particles'.

At the beginning of Euclid's *Elements*, a point is defined as that which has no part (HEATH, 1908; 1926, p. 155). What it means for something to have (no) parts is not defined; the reader is supposed to know what that means, at least roughly, to have some idea of what a point might mean. So, these abstract, partless parts are introduced at the very beginning and are clearly a fundamental notion for doing Euclidean geometry.[3]

Likewise in physics: the notion of elementary particles – physical parts without parts – is indeed a fundamental one. The meaning of 'atom' is uncuttable, but with the progress of science, it turned out that what had previously been considered as atoms could be split after all. Subsequently, the atom lost its status as a truly elementary particle. The same happened later to

[3] Mathematics has many more terms that refer to fundaments, such as: axiom, base, basis, element, fundamental matrix, and root.

its most massive constituents: the protons and neutrons, which we now think of as composed of three quarks each. Electrons are still on the table for being truly elementary particles. The Standard Model of particle physics offers many more such candidates: while (supposedly) partless, they are not few. So, we see that the meaning of 'particle' has shifted considerably over the history of physics, just like the fundamental physical concept of 'energy' has (COELHO, 2009).

2. Pluralism about fundaments

As mentioned before, one drawback of the etymology of 'fundamental' is that it refers to the foundation of a building. Although a building can have many stories, possibly several underground ones, it only has one true foundation. This invites the search for ultimate foundations, which may turn out to be a misguided project, as we'll see.

2.1 Fundamental to whom and for what purpose?

The property 'being fundamental' is much like 'being funny', 'being beautiful', or 'being important', in the sense that they all invite follow-up questions. Fundamental (or funny, beautiful, or important) to whom? And in what context? Something is fundamental to someone (possibly a group of people) in a context.

The observation suggests that fundamentality is not an inalienable property of certain aspects of reality. But this suggestion flies in the face of an influential account due to LEWIS (1986): he argued that when a property or relation is fundamental (or 'perfectly natural'), then that property or relation is intrinsic; otherwise it is extrinsic. While LEWIS did not aim to investigate whether fundamentalness is intrinsic, he simply took it to be the very signifier of intrinsicality. To illustrate the sense in which he understood fundamentality, he considered the "short list of 'fundamental physical properties'" (p. 60).

Nevertheless, many scientists and some philosophers have made remarks that illustrate that fundamentality is context-dependent.[4] For example, commenting on specialization in biology, BARTHOLOMEW (1966, p. 39) wrote: "[T]he members of each specialty tend to feel that their own work is fundamental and that the work of other groups, although sometimes technically ingenious, is trivial or at best only peripheral to an understanding of truly basic problems and issues."

It is not obvious that simplicity or fundamentality can be agent-relative when they apply to concrete referents. But whether we *treat* something as a composite notion does depend on our background knowledge and purposes. To me, this suggests that fundamentality is in the eye of the beholder.

To prepare our minds for the possibility of pluralism about what is fundamental, we may apply the metaphor differently. Think of science (or just physics) not as a single building, but as a city, which grows organically and in which some but not all quarters are connected. Hence, if we start looking for the foundations of (a) science, we should be prepared to find many of them – from medieval ones to those still under construction.

2.2 Hierarchy of the sciences

'Fundamental' can be used as a comparative notion. When comparing two theories, for instance, we might conclude that one is more fundamental than the other. The context, which will influence our criteria for doing so, is often left implicit. If we compare many theories in a fixed

[4] See WEATHERSON & MARSHALL (2018, section 3.2) for an overview of counterarguments to LEWIS.

context and it turns out that one is the most fundamental among those under consideration, this invites the leap to an absolute claim: "this theory is fundamental, whereas the others are not". If all members of a discipline agree, this impression may be stronger still. But that does not suffice to justify the leap.

A necessary first step in engaging critically with implicit ideas is drawing them out. **Fig. 2** is helpful in that regard, since it represents a common idea about the hierarchy of the sciences. Despites its prevalence, not all scientists know its history: it goes back at least to Auguste COMTE, a nineteenth century positivist philosopher and pioneer of sociology. COMTE (1830, Vol. 1, Lesson 2) listed the sciences by decreasing age, development, and generality as follows:

mathematics, astronomy, physics, chemistry, physiology, and sociology.

COMTE added that his 'rational hierarchy' of the sciences was at the same time a hierarchy of the phenomena that each of them describes. This suggests that the phenomena that are studied in the special sciences can be reduced to those of more general ones. Comtian reductionism implies that the sciences form a unity, with physics grounding all other empirical sciences (as in **Fig. 2**), and mathematics providing the foundation for physics.

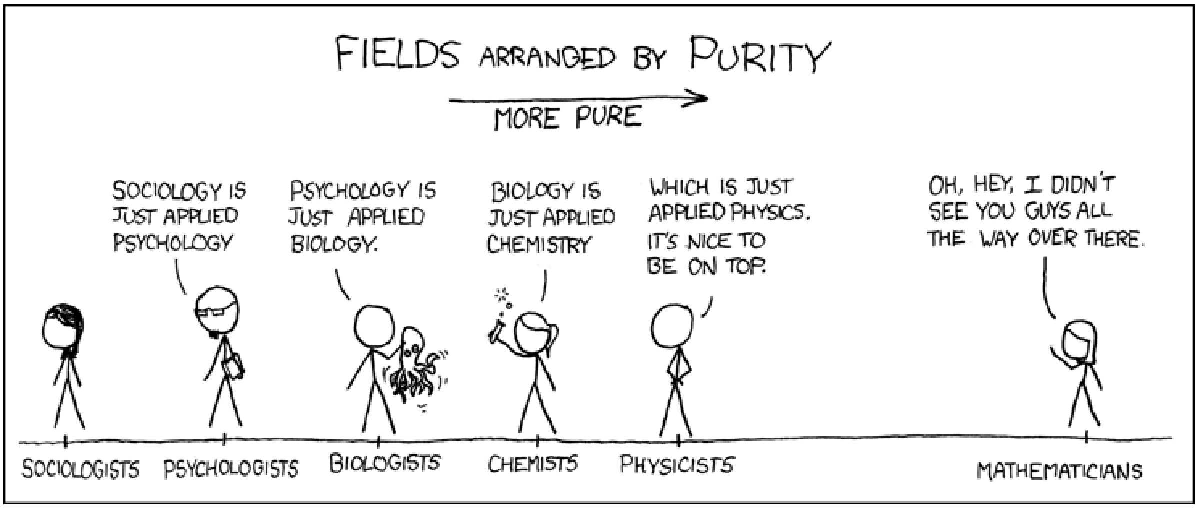

Figure 2: COMTE's hierarchy depicted in a comic by Randall MUNROE (2008).

COMTE does not tell us how to measure the age, development, or generality of a science. We are expected to take his word for it that all these different measures yield the same ordering. In addition, accepting his theory requires believing in the harmony between the rational parts of the sciences and their concrete subjects. Are the two projects of natural philosophy one and the same after all?

On closer inspection, the positivist view about reductionism largely evaporates. Connections between the sciences are too diverse in strength and kind to claim victory for reductionism and unity. Zooming in, this also applies within the sciences: (i) a science is not monolithic and (ii) connections between its subfields vary in tightness and kind.

Let's focus on physics to illustrate both claims:

(i) Rather than one system of principles and methods, physics is a patchwork of theories, models, and methodologies. Some physical theories start from their own, largely autonomous set of postulates. To name just four of them: Newton's laws, the laws of thermodynamics, the postulates of special relativity, and those of quantum mechanics.

(ii) There is some scaffolding between various physical theories and models, but it is scarcer than we would like: there is a lot of 'missing physics' (WILSON, 2009). Prompted by the combination of concepts and idealizations of different physical theories, many questions arise to which there simply is no answer.

Since the prevalent post-Comtian picture seems flawed, we should develop a more accurate alternative.

2.3 Mapping physics

For a class on emergence, I attempted to draw the subfields of physics and related disciplines: see **Fig. 3**. Connections between the subfields and theories are not drawn, to avoid overcrowding the diagram; models and equations are left out for the same reason. I do not think of this as a definitive representation, but as a conversation starter. What would your map of physics look like?

I started with Newtonian mechanics in the middle, as it is undeniably central to physics. Then I tried to complete the diagram in an intuitive way. The horizontal direction does not represent an order, but is merely based on associations of topics. Think of the rightmost edge as connected to that one the left, like a cylinder, such that optics is close to astrophysics and dark matter to dark energy.[5]

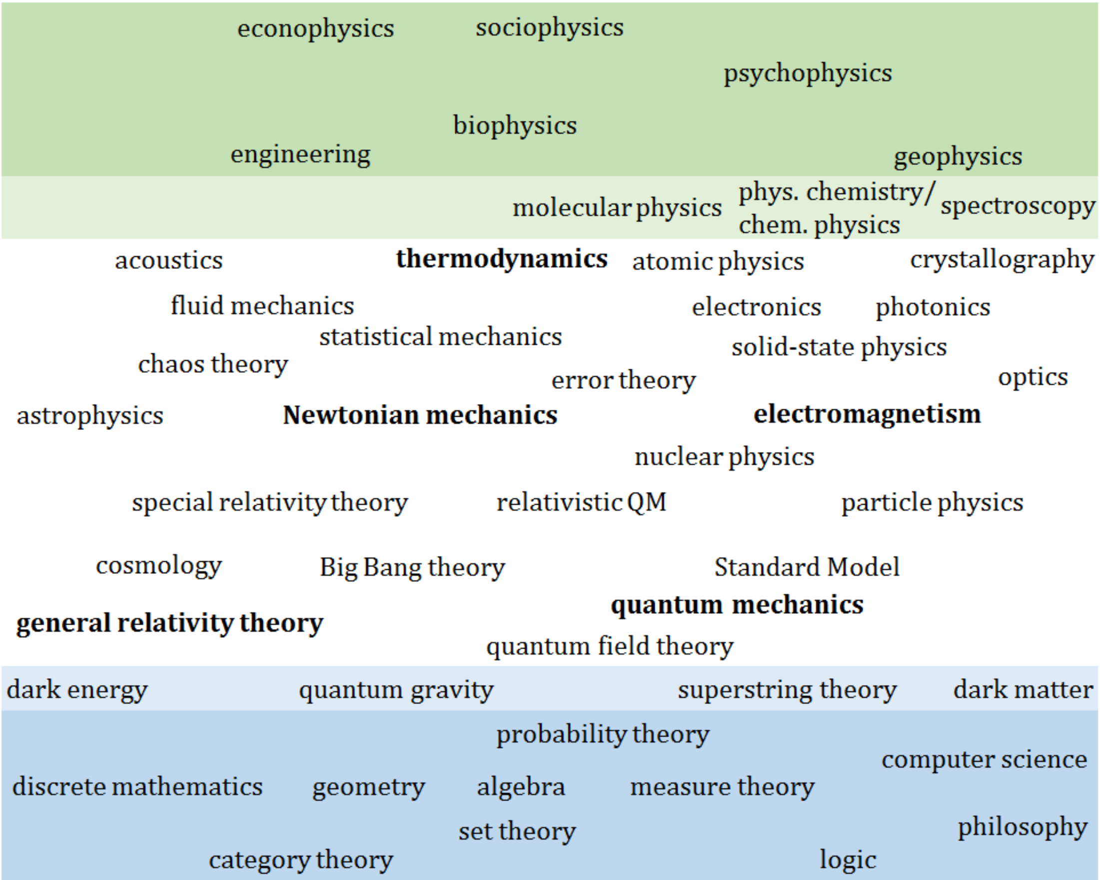

Figure 3: A patchwork view of physics showing more applied theories and subfields towards the top.

[5] The horizontal direction may be a low dimensional projection of a higher dimensional web of connections, such as the ones brought to light by citation network analysis.

As discussed at the start of this essay, actual fundaments are found at the bottom position and are concrete. So, if we expect to find them in **Fig. 3**, we should expect to find fundamental notions and subfields at the bottom, corresponding with concrete things. But these two properties – fundamental and concrete – don't seem to match well; if anything, they seem anti-correlated.

The white part in the middle indicates theories and subfields that are central to physics. Dark blue theories are applied in central parts of physics, whereas dark green theories apply methods from physics to questions in other fields.

To be a physical theory at all, the formal part of the theory needs to be supplemented with rules of correspondence between theoretical terms and what is empirically accessible. This brings us to a grey zone or, rather, the light blue zone in **Fig. 3**. Because of this fuzziness, there is no first (most fundamental) empirical or physical level. The light green theories are borderline, too: it could be debated whether they belong to physics (rather than a different empirical science). So, also the clear demarcation between physics and other fields evaporates on the patchwork view.

The vertical organization in **Fig. 3** appears to be stratified: is it just a refinement of COMTE's hierarchy within physics? I think it is doubtful that all meanings COMTE assigned to his hierarchy match up. In addition, my diagram is not intended to be read in a reductionist way.

We will now explore two possible ways of making explicit what the vertical dimension of **Fig. 3** could represent; bottom to top could range (i) from abstract to concrete or (ii) from simple to complex.

(i) It is my impression that the more we move towards the bottom of the diagram, the higher the abstractness of the degrees of freedom involved (more distant from daily experience and our manifest image of the world).

(ii) The scaffolding between physical theories (not shown) consists of bridge laws that provide partial 'translations' between theories.[6] We can use the scaffolding to investigate the relative complexity of two theories. This is a two-place function that depends on what needs to be expressed (the 'higher-order' theory) and what is assumed (from the 'lower-order' theory).[7] In practice, we can only find an upper bound for the value, as a better translation may yet be found. In addition, it co-depends on the metalanguage in which the translation is evaluated. And since many pairs of theories lack bridge laws, this leads to a partial order at best.

Notice that we haven't defined either measure. Although this would be an interesting question to pursue, I will not do so here. Hence, it remains an open question whether such measures would agree at least approximately on the ordering – as COMTE silently assumed. In addition, it remains speculative whether either of the proposed measures would correspond to my intuitive ordering as mapped out in **Fig. 3**.

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[6] Since physical theories can be inconsistent relative to each other, the connections typically fall short of reducing one theory to the other. They do give an interpretative framework that can help us to understand said inconsistencies (*e.g.*, stipulating a correspondence principle based on a limit operation).

[7] The terminology of higher- and lower-order theory is invoked only to indicate the direction of the attempted translation, not as an intrinsic, reductive relation between them.

2.4 *Science as a platform game*

"The constructionist hypothesis breaks down when confronted with the twin difficulties of scale and complexity". Philip W. ANDERSON (1972, p. 393)

Many ties appear in the vertical ordering of **Fig. 3**, so comparing fundamentality does not lead to a total order. The cause of this may well be that physics does not offer a single context. Physics has many goals and purposes (*cf.* section 2.1): describing apparent positions of stars and predicting eclipses; explaining why rainbows occur; creating electronic sensors.

Depending on the purpose at hand, physicists' judgment of what is fundamental may well vary. This is problematic only if we insist that fundamentalness is the epitome of an intrinsic, ontological basis – which is too often assumed without argument.

When scientists want to develop a theory about a certain phenomenon, they take the liberty of using any physical referents (units, for instance), terminology, and mathematical tools suitable for that goal. If they would restrict themselves to a previously selected set of basic notions, they often wouldn't even be able to formulate the relevant question, let alone solve it. We may imagine science as a kind of platform game, but there are not nearly enough ladders to connect all the levels (**Fig. 4**). We must allow ourselves to jump in at the level of interest if we want to start playing at all. And bold leaps are required if we attempt to combine different theories. (The complexity measure hinted at in the previous section is like our current best time for getting from a specific platform to another one.)

While scientists make progress with the project at hand, they also revise their methodology, language, and formalism. Sometimes they discover deep connections to other theories and subfields, thereby developing the scaffolding between the theories. This is very valuable, but since these relations go both ways, it would be naïve to read it as evidence for our science being built up starting from a given fundament. If there is a bottom level at all (on any given measure), it is as much under construction as the higher platforms and the ladders between them.

Moreover, some ways of providing scaffolding may be so versatile, that they turn into central parts of physics themselves. This seems to be case for dimensional analysis, for instance. Moreover, it offers one way of unifying the two projects of natural philosophy: while dimensional analysis is suitable for abstract, mathematical treatment, it is really grounded in empirical operations on concrete systems that allow relevant comparisons to be made (SONIN, 1997; 2001; WENMACKERS, forthcoming).

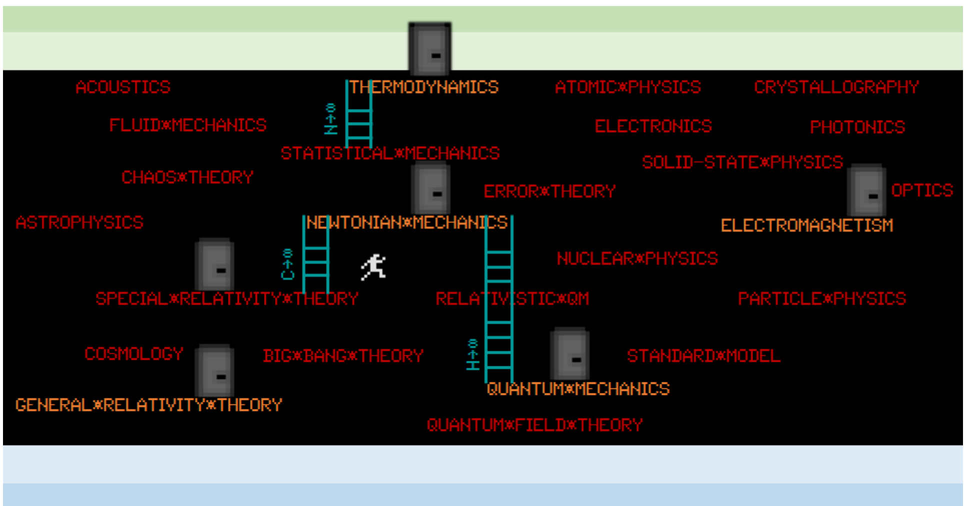

Figure 4: Physics as a platform game, with the scientist taking a leap.

3. Balanced realism

Finally, I would like to explore the possibility that any ascription of 'fundamental' to presumed ontological things, relations or processes is mistaken.

We already remarked that strong intersubjective agreement on something is suggestive of an objective interpretation, though insufficient to prove that it is more than an epistemic notion (section 2.2). This is true for concepts like chance or determinism, as well as for fundamentality. There is no compelling reason to reify them, reading them in the world. What is conceptually helpful and pragmatically fruitful to us need not be enshrined into a permanent metaphysics, since both conceptual helpfulness and pragmatic fruitfulness are agent- and purpose-relative, and even the collective purposes and standards of science do change over time.

The history of science should make us cautious: our currently best supported theory is unlikely to be the ultimate one. As KASNER & NEWMAN (1940; 1989, p. 193) pointed out: "The testament of science is so continually in a flux that the heresy of yesterday is the gospel of today and the fundamentalism of tomorrow."

Both mathematicians and physicists select ingredients for their theories based on intelligibility, minimality, and beauty. For physicists, there are additional criteria, with empirical adequacy trumping all others. In the words of WHEWELL (1847, Vol. 2, p. 57), this is how a physical scientist ought to act: "[I]f the results of [experiment and observation] contradict his fundamental assumptions, however ingenious, however symmetrical, however elegant his system may be, he rejects it without hesitation."

This comes close to the Popperian notion of falsificationism: the idea that science proceeds by falsification of mistaken theories and hypotheses. It follows from this that science never shows any theory to be true, no matter how strongly it has been corroborated by evidence and no matter how much its mathematical elegance appeals to our rational minds.

This brings us to a central question from philosophy of science: should we be realists about what our best scientific theories seem to tell us about the world? Those who answer 'yes' are divided along the lines of the two main projects of natural philosophers – fundamentals principles versus fundamental particles:

(1) Entity realists argue that we should be realists about the entities of our theories that are instrumentally successful.

(2) Structural realists argue that we should be realists only in a weaker sense: we should believe merely that the abstract structure of our best theories corresponds to (or approximates) a structure of the physical world (LADYMAN, 2014).

We can also ask about the reality of fundamentality itself. Let's focus on the well-corroborated Standard Model: it is a gauge quantum field theory (abstract) that comes with candidate elementary particles (concrete), many of which have been empirically confirmed.[8]

So, should we take the stance of structural realism towards electrons? Although his remark precedes the current theory, EDDINGTON (1928, p. xiv) seemed to agree: "To a request to explain what an electron really is supposed to be we can only answer, 'It is part of the A B C of physics.'"

[8] Since the Standard Model is a quantum field theory, it's a matter of debate whether it fits with a particle ontology at all.

An entity realist, on the other hand, might apply HACKING's (1983) slogan and reply: since we can effectively spray electrons, they exist. But even entity realists need not (and I argue: should never) reify fundamentality. Even if electrons are assumed to exist, they need not be a *fundamental* part of reality. Saying that they exist *and* are fundamental in reality seems to conflate the epistemological and the ontological sense of fundamentality, belonging to two different projects.

What remains to be done for physical fundamentality has already been achieved for the notion of physical indeterminism. In his work on exchangeability, de Finetti showed in a precise way that in doing away with chance, while proceeding to act as if it existed, nothing is lost (DIACONIS & SKYRMS, 2018, Chapter 7). Although a lot needs to be done in the case of fundamentality, I offer this successful example as a source of inspiration and optimism.

Failing to make the distinction between existence and existence as a fundamental part may be fine in the short term, but there is reason to believe that it leads to stasis in the longer term. The history of physics has some interesting examples to illustrate this point: neither proponents of the continuous ether, such as J.J. Thomson (NAVARRO, 2012), nor anti-atomists like Ernst Mach (BLACKMORE, 1985), changed their views when quantum mechanics was developed. While J.J. Thomson clung too much to his preferred ontology, Mach erred in the other direction. In both cases, it appears that failing to direct fundamentality judgments properly may contribute to the phenomenon of science proceeding one funeral at a time.

4. Concluding remarks

When we restrict ourselves to active physicists (in a particular subfield), we may find broad consensus on what is fundamental. Yet, this is not sufficient to take fundamentality as an ontological concept. We have explored the possibility that fundamentality is not a property of certain aspects of reality, but rather an agent- and context-dependent notion. Although this alternative interpretation is not generally accepted, it does seem to be a promising one. If we agree to reinterpret fundamentality along these lines, we learn to be careful when interpreting our best scientific theories realistically. Even if it is justified to interpret an entity, relation, or structure realistically, there is reason to believe it is not justified to interpret that entity, relation, or structure *together with* the predicate 'fundamental'.

This allows me to explain the title of this essay: while we look for what is fundamental, we should not jump to conclusions about the physical world once we believe we've found something. 'Fundamental' is best left as an epistemic term, rather than an ontological claim (even if the referent is interpreted realistically).

To fully show you the motto's relevance for our present topic, I end with the original passage in which WHITEHEAD offered it (1920, p. 143):

> "Nature appears as a complex system whose factors are dimly discerned by us. But, as I ask you, Is not this the very truth? Should we not distrust the jaunty assurance with which every age prides itself that it at last has hit upon the ultimate concepts in which all that happens can be formulated? The aim of science is to seek the simplest explanations of complex facts. We are apt to fall into the error of thinking that the facts are simple because simplicity is the goal of our quest. The guiding motto in the life of every natural philosopher should be, Seek simplicity and distrust it."

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