Progress in elementary particle physics in recent decades has weakened the status of the observable phenomena. Empiricist positions in philosophy of science, which put particular emphasis on the pre-eminence of the observable regime, are affected by this development. The present paper analyses the philosophical implications of the reduction of the observable implications of scientific theories for the conception of constructive empiricism. The latter turns out to have serious difficulties for providing a satisfactory motivation for scientific inquiry in the context of contemporary particle physics. The problem may be overcome by a specific modification of the conceptual foundations of constructive empiricism.

1: Introduction

Objections to scientific antirealism are often based on alleged continuities between scientific objects and the objects of everyday life. In this vein, scientific realists have stressed the implausibility of denying reality to scientific objects which lie barely beyond the visibility limit, they have questioned the possibility of drawing satisfactory limits of the observable regime [Maxwell 1962] and have argued that scientific objects which can be manipulated more or less like observable objects should be called real on experimental grounds [Hacking 1983]. The present article will approach scientific antirealism from the opposite angle. It will discuss the viability of scientific antirealism in the context of contemporary elementary particle physics, where theory building is at its most abstract and the equation of the posited scientific objects with the objects of the observable world is most questionable. While the scientific antirealist does not feel much pressure from an intuition-based realist stance in that context, she faces a different problem that is directly related to the remoteness of the scientific field in question. The problem is based on the simple fact that scientific antirealism puts particular emphasis on the observable phenomena, either ontologically, by interpreting all scientific statements as statements about the observable regime, or epistemologically, by restricting access to truth to the observable regime. Elementary particle physics in recent decades has witnessed a significant reduction of the extent and theory-independent relevance of its characteristic empirical phenomena. This reduced scope of the observable phenomena, which will be described in more detail in section 3, can affect their capability for providing a satisfactory explanatory basis for the scientific process along the lines suggested by empiricism.

Problems for antirealism can arise at two different levels. In strong versions of scientific antirealism, ontological antirealist assertions may come under pressure: a philosophical position that reduces all theoretical structure to information about the observable regime arguably looks less plausible in scientific contexts where highly complex theories are posited to explain a dire minimalist set of empirical data. At another level,
ontological as well as epistemological antirealist conceptions are affected: the reduced theory-independent significance of characteristic observable phenomena in highly theoretical scientific fields may lead to an erosion of the motivational basis of scientific research. Classic motivational strategies which are based on the observable phenomena may be expected to lose power. The present work will focus on the question of motivation in the context of the classic formulation of epistemological antirealism, constructive empiricism (CE). After a general characterisation of the motivational question in section 2, section 3 will explicate the ways in which contemporary particle physics affects the status of the observable phenomena and raises new problems for the understanding of scientific motivation. Sections 4 and 5 will analyse the specific case of CE and will discuss some potential strategies to solve the problem in accordance with constructive empiricist principles. Finally, section 6 will suggest a modification of CE that may be better suited to account for the altered status of observable phenomena in contemporary particle physics.

2: Motivation

When scientists invest their time and taxpayers’ money into the solution of some scientific problem, one wants to assume that they have a universally acceptable reason for doing so. While individual scientists may be guided by strictly personal motives like the ‘gold, fame and glory’ alluded to in [van Fraassen 1980], a sound scientific field should allow the construal of rational reasons for the pursuit of scientific research in the field which are based on a given framework of universal values and dispositions and can be agreed upon by scientists and interested science-observers.¹

Generally, two classic universal motives for scientific inquiry can be distinguished. Scientific research can provide knowledge about the world and it can be useful for practical improvements of human living conditions. While the second motive is sufficiently pragmatic to remain largely unaffected by the conceptual discussions of philosophy of science, the concept of knowledge and the related concept of truth are subjected to intense philosophical debate. In the following, scientific knowledge shall be understood to be represented, *grosso modo*, by approximately true statements whose truth has been ascertained to a reasonable extent. On this basis, realists and antirealists disagree on the question of which part of the world confirmedly true scientific statements can refer to. The scientific realist takes well confirmed scientific statements on unobservable scientific objects to be (probably and approximately) literally true. The scientific antirealist, on the contrary, claims that confirmedly true scientific statements can only refer to objects of the observable regime.

Scientific antirealists therefore only accept a reduced basis for the motivation of scientific activity by the quest for knowledge about the world. Let us consider, for example, an instrumentalist position that rejects a literal interpretation of scientific statements and asserts that all scientific statements are solely statements about the observable world. From this perspective, an explication of the motives for developing and testing a scientific theory must rest entirely on the significance of the theory’s observable implications. While the realist can claim that Rutherford’s scattering experiments were motivated by the quest for knowledge about the fundamental constituents of matter, the instrumentalist must be satisfied with the statement that they were motivated by the quest for knowledge about the scattering patterns visible on the screen or related observable phenomena. Obviously, the importance of a scientific field depends on the relevance of the phenomena it sets out to analyse. The

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¹ This does not imply, obviously, that everyone agrees on the overall assessment of the pro’s and con’s of a specific scientific endeavour.
question whether science can or can not provide knowledge about unobservable objects and structures therefore may affect the assessment of a scientific field’s importance, in particular in cases where the significance of the characteristic observable phenomena appears questionable. The recent developments in elementary particle physics provide a good example and for this reason shall be examined in greater detail in the following section.

3: The Marginalisation of the Phenomena

The status of the observable phenomena in contemporary fundamental microphysics differs substantially from the situation 50 years ago. Throughout the first half of the twentieth century, the development of fundamental microphysical theories was of utmost importance for an understanding of the observed world. While the experiments designed to test specific aspects of the microphysical theories often relied on subtle and minute phenomenological output, the tested theories as a whole had very substantial observable consequences. These were utilized in technical developments that shaped everyone’s life. From the utilization of X-rays to the building of nuclear bombs and power plants, from the development of television to the use of neutron physics in modern medical treatments, technological progress was and still is based on the fundamental theoretical concepts developed in the first half of the 20th century.

Given these circumstances, science could easily be seen as being motivated by its observable implications. It was plausible to claim that the primary relevance of microphysics lay in its potential to create, control and understand observable phenomena rather than in its posit of some weirdly behaving unobservable objects. The argument for this claim could be given at two levels. From a utilitarian perspective, it could be asserted that science had adopted the role of an auxiliary discipline of the technical evolution and was justified primarily by the technical achievements it made possible. Choosing a more knowledge-oriented perspective, the empiricist could argue that the significant observable phenomena created by experimenters and technicians constituted an important part of reality and therefore deserved scientific analysis.

Particle physics today conveys a quite different picture. The quest for consistent unified theories of physical forces has led to increasingly complex and predictive theories whose characteristic length scales lie many orders of magnitude below the scales relevant in traditional nuclear physics. At the same time, the inverse proportionality between the available kinetic energy per particle and the testable distance scale has provided a straightforward strategy to test ever smaller distance scales by building ever larger particle colliders. These developments have joined in supporting a process I want to call the marginalisation of the phenomena: the significance of the observable phenomena to be described by the new theoretical schemes has decreased dramatically in modern particle physics. Four interrelated points may be listed to summarize this shift:

1: Particle theory has lost its direct relevance for technological progress. The deep inelastic scattering at high energies that takes place in collider experiments produces highly instable particle states whose life span is far too short to offer any perspective for technological utilisation. The theories tested in these experiments thus don’t have any technological relevance today and there are no indications that this might change in the foreseeable future.

2: The size of the experiments necessary to produce new phenomena is steadily increasing. Today it requires the multi-billion-dollar construction of a many kilometres long particle collider and the sustained work of thousands of experimentalists to test physics at new energy scales. The characteristic experimental signatures of advanced particle theories like
grand unified theories or string theory even lie largely or entirely beyond the reach of any experiment imaginable today.

3: The observable phenomena acquire their significance solely in the context of the theories developed to explain them. The observed or expected phenomenological implications of theories like the particle physics standard model or supersymmetry are limited to a few unusual lines on a set of photos taken in a collider experiment. The specific structure of these lines would remain entirely irrelevant if judged solely in the context of observable phenomena. Their relevance is based entirely on their capability to confirm or refute scientific theories.2

4: The theoretical schemes involved get richer and more complex. The richness of the theoretical structures developed in particle physics stands in stark contrast to the minimalism of their observable implications.3

The marginalisation of the phenomena in particle physics has altered the balance between theory and the observable phenomena. The motivational implications of this shift become apparent in the context of a theory’s ability to predict observable phenomena. The classic situation, where the construction of scientific theories could be understood as an instrument for making genuinely significant predictions, has given way to a situation where predictions of per se negligible phenomena get their relevance solely from the fact that they tell something about the viability of a theory. The observable phenomena turn from the primary subject of scientific curiosity into a means for developing and confirming theories whose genuine significance cannot be understood in terms of these phenomena themselves. In this new scientific environment the instrumental qualities of theories lose much of their motivational power. A theory’s ability to structure and predict observable phenomena cannot provide good reasons for doing research in that field if the phenomena in question lack all independent significance. Consequently, any convincing motivation for theory construction has to be based on some quality that gives relevance to the theory itself and goes beyond the mere characterisation of the minimalist phenomenological surface.

4: The Role of Motivation in Constructive Empiricism

In the following, the specific implications of the motivational problem of particle physics shall be analysed in the context of the currently pre-eminent antirealist position, constructive empiricism (CE). CE is of particular interest for an analysis of motivation for two reasons. Firstly, it is especially vulnerable to motivational arguments since it lacks a defensive strategy that is open to stronger versions of scientific antirealism. An antirealist who rejects a literal interpretation of scientific statements can make the point that a physicalist understanding of scientific statements merely represents a specific language choice forscientific theories. In a more traditional scientific setting, however, the empiricist could explain the significance of the resulting theoretical developments once again by referring to the visible phenomena.

2 Obviously, empirical evidence has always been valued as a basis for the evaluation and development of scientific theories. In a more traditional scientific setting, however, the empiricist could explain the significance of the resulting theoretical developments once again by referring to the visible phenomena.

3 The presented points apply primarily to those parts of particle physics which are tested in collider experiments. While it is clear that the stated points do not affect applied or technical physics, the question to what extent the marginalisation of the phenomena applies to other branches of fundamental physics is a complex one, a full discussion of which goes beyond the scope of this article. Cosmology, the second main branch of fundamental physics, in some aspects remains tied to visible phenomena in van Fraassen’s sense. Other parts of cosmology which deal with the early universe, however, seem to have little worth for the prediction of genuinely significant visible phenomena. While the case is less straightforward in cosmology than in particle physics, it may be possible to construe the marginalisation of phenomena as a general tendency that is linked to the increasing abstractness of fundamental physics.
characterising a situation that could be equally described in phenomenalist terms. If the choice between the two approaches merely is a matter of language, however, no substantial motivational disadvantage of phenomenalism compared to a physicalist understanding can possibly occur. The critic of antirealism can retort that the phenomenalist construal of a physicalist description (a) cannot be coherently done and (b) even if it could, would constitute just a veiled variation of the phenomenalist description and would not resemble the realist stance whose motivational advantage she stresses. This, however, leaves her with the task of defining precisely the difference between the antirealist’s ‘pseudo-realism’ and her own realism. This discussion can be skipped when discussing CE since the latter agrees with scientific realism in endorsing a literal understanding of scientific statements and therefore has to concede that an acknowledgement of the truth of scientific statements could, in principle, open up new motivational perspectives. The second reason for being interested in the motivational question in the context of CE is related to CE’s prominent use of the concept of the ‘aim of science’, which will turn out to be entangled with the concept of scientific motivation in a complex and interesting way.

CE claims that science aims at empirical adequacy (EA). The ‘aim of science’, given the way the concept is used by CE, denotes a technical criterion of scientific success and must be clearly distinguished from the motivation to do science. Taking up the example of chess deployed in [van Fraassen 1980], the universal motives for getting involved in chess may be the fascination of complex thinking and competitive situations; personal motives to play the game might in addition hinge on arguments related to gold, fame and glory; the aim of chess, however, is to checkmate the opponent.

Though motivational questions are not directly addressed by CE, they can be relevant for CE in two ways. First, specific motives for carrying out a certain research programme can imply scientific behaviour that is at variance with the aim of EA. Wherever that is the case, the motives in question can be directly tested against CE by looking at the scientists’ behaviour. Second, in cases where the claim that science aims at EA is compatible with the scientists’ assessments of their theories’ success within the given research programme, CE may still fail to make sense of the way scientists evaluate the significance of the fundamental scientific questions which stand behind the pursuit of that research programme. CE’s claims then would provide a valid characterisation of the scientists’ working routine but would be too weak for a full understanding of the scientific process. Both specified problems can be best discussed by considering their role in some examples from actual science. The following comparison of the motivational structures of palaeontology and nuclear physics will demonstrate that CE in fact draws much of its credibility from its ability to answer questions of scientific motivation in important cases of scientific research.

Let us first examine the case of palaeontologists who try to reconstruct dinosaurs from excavated bones. Their theories are concerned with the physiology and behaviour of the dinosaurs whose bones have been found. They seek to develop theories that give full descriptions of those qualities for specific dinosaur species. Two aspects of this scenario are important. On the one hand, palaeontology deals only with observable objects, which means that empirically adequate and true statements are conflated. On the other hand, palaeontologists face an unbridgeable gap between all possible empirical evidence and all empirical evidence possibly accessible from the beginning of their scientific activity onwards. Much of the evidence about dinosaurs that had been available 65 million years ago has decayed without leaving any trace today. Consequently, the palaeontologist’s maximal observational horizon does not allow the testing of full EA but only of the significantly more modest ‘EA(+), which denotes ‘empirical adequacy with respect to all observations open to

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4 To keep the argument simple, we use a rather schematic construal of palaeontological research.
human beings from now on’. In the case of considering palaeontology, van Fraassen’s claim that all alleged empirical tests of truth are merely tests of EA thus can be transformed into the claim that they are merely tests of EA(+).

Do palaeontologists therefore aim at EA(+)?

Let us imagine the discovery of a dinosaur tooth that does not fit in with any of the known dinosaur families. It might well be the case that this tooth is the only part of a species of a given dinosaur family that has survived on earth, so that scientists cannot possibly get more information about that family than what is contained in the discovered tooth. Any theory about the concerned dinosaur that is compatible with the tooth itself therefore must count as a reasonable candidate for a theory that satisfies EA(+). Hence, the construction of any such theory would be scientifically desirable if science aimed at EA(+).

It is obvious, however, that a theory that conjectures the entire physiology and behaviour of a dinosaur based on one tooth must be so dramatically underdetermined by the evidence that most of its claims, though potentially EA(+), will most likely be false. Palaeontologists clearly would not accept such overly underdetermined and presumably false theories and in the given case would prefer to abstain from endorsing any exhaustive theory about the new dinosaur’s physiology. Two conclusions can be inferred from that behaviour. At the motivational level, it suggests, unsurprisingly, that palaeontologists are motivated by the quest for the truth about dinosaurs. At the technical level, theory acceptance in palaeontology turns out to involve an assessment of the degree of underdetermination of theory by the available data that reaches out beyond the empirically accessible, which is at variance with the claim that palaeontologists aim at EA(+). Palaeontology thus aims at truth rather than EA(+) in accordance with its motivational background.

Since EA resembles truth extensionally for all statements about observable objects, including dinosaurs, CE is not directly affected by the previous argument. Palaeontologists who are motivated by the quest for the truth about dinosaurs can reasonably aim at EA. What the palaeontological example establishes, however, is the fact that science can deploy the assessment of its theories’ degree of underdetermination as a method of deciding about theory acceptance that reaches out beyond the empirically accessible. In this light, any inference from the empirical inaccessibility of truth to the statement that weaker aims of science are compatible with the scientific process, must rely on an additional assumption. It must take for granted that assessments of underdetermination are not part of the scientific process in those scientific fields where the suggested weaker aims of science are distinct from aiming at truth. CE’s statement that science aims at EA consequently must rely on the claim that assessments of underdetermination are irrelevant for theory acceptance in all theories with unobservable objects, where the conflation of EA and truth breaks down. But why should such assessments be irrelevant in scientific theories with unobservable objects if they constitute a crucial part of scientific reasoning in fields like palaeontology?

Nuclear physics opens the gap between truth and EA and closes the gap between EA and EA(+). Since the time invariance of fundamental natural laws is considered a core principle of physics, microphysical phenomena guided by natural laws are expected, in principle, to be reproducible at all times. (We leave aside, for the moment, those parts of microphysics where cosmology comes into play.) EA(+) thus is conflated with EA and the gap between EA and truth becomes the only characteristic aspect of the status of a scientific

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3 Of course one can deny the relevance of the statement that the theory has chances to be EA(+) on Popperian grounds by pointing out that EA(+) can only be expected to apply under the condition that many aspects of the theory are de facto not experimentally falsifiable, which would render the theory’s claims unscientific. This, however, already presupposes an answer to the fundamental question we face in the present context: In which cases can underdetermination be considered an acceptable characteristic of a scientific theory and in which cases does it destroy the theory’s scientific value?
theory that must be grasped by an assessment of underdetermination. If we look at the scientific praxis in nuclear physics, it is striking that, in agreement with the claims of CE, underdetermination is NOT used in any significant way as an argument against the acceptance of empirically confirmed theories. Once a theory has been shown to save the observed phenomena (and maybe to have some other qualities like predictive force, coherence, etc), it is scientifically accepted irrespective of the question how many other, empirically equivalent theories might be able to play the same role. As a matter of fact, microphysicists would run into serious problems if they had to carry out assessments of underdetermination, because the counterintuitive properties of microphysical objects undermine the stable foundation of ontological existence claims. The resulting philosophical disputes about possible ontological interpretations of quantum theories render an assessment of the concerned theories’ degree of underdetermination far more difficult than in theories about dinosaurs, where one can rely on the assumption that the set of potentially viable theories does not transgress the set of theories based on our intuitive notion of heads, legs or tails.6

Palaeontologists address the question of underdetermination because the universal motives for doing research in palaeontology rely on the quest for truth. If nuclear physicists abstain from assessments of underdetermination, which could provide the basis for belief in the truth of its statements about unobservable objects, this suggests that they can resort to other sources of motivation. In fact, nuclear physics offers one powerful source of motivation that is not available to the palaeontologist: predictive power. Palaeontology cannot easily base its justification on viable predictions, precisely because it focuses on bygone observable objects and therefore highlights the difference between EA(+) and EA. In the context of nuclear physics, on the other hand, predictive power plays a crucial motivational role. Physical predictions allow us to control the investigated phenomena, provide the basis for finding new phenomena and eventually may lead to the technical utilisation of the discovered principles. If a physical theory is able to describe and predict a significant regularity in the phenomenal world, this therefore can count as sufficient justification for taking that theory seriously, irrespective of questions concerning the truth of its statements about unobservable objects. In this context, it is difficult to deny that the claim that scientists aim at EA looks more plausible than the claim that they aim at truth.7 The quest for truth may still play a role in motivating nuclear physics, but the definition of the aims of scientific research in the field does not depend on it.

The comparison of the motivational structures of the two discussed research fields suggests a coherent overall picture. Only those scientific disciplines whose predictive power does not play a central role in motivating theory construction must fall back on judging their theories’ value primarily based on their truth value and consequently have to resort to an assessment of their degree of underdetermination. Highly predictive theories which derive their value from their predictive power don’t have to meddle with the question of underdetermination. Physics and palaeontology choose substantially different kinds of scientific credentials depending on the chances of vindicating them within their respective

6 [McMullin 2003] suggests that the plausibility of constructive empiricism is far more dependent on questions of micro-ontology than its exponents are willing to admit.

7 It should be noted that the emphasis put on the question of assessments of underdetermination in this section provides stronger reasons for the claim that scientists aim at EA than van Fraassen has given himself. [van Fraassen 1985] concedes that the claim that scientists aim at truth would be compatible with the scientists’ behaviour but would involve a higher amount of ‘empty strutting and posturing’ than the claim that they aim at EA. The palaeontological example, to the contrary, has made the point that aiming at truth should be manifested by using a specific technique to look beyond the empirically testable, namely the assessment of underdetermination of theory building by the available empirical data. The observation that scientists do NOT apply this technique in cases like nuclear physics provides an explicit argument against the thesis that scientists aim at truth in that context.
scientific context. The validity of EA as the aim of scientific theories thus relies on the careful fine-tuning of EA’s definition in order to cover various quite distinct motivational contexts of scientific research. In both contexts discussed above, palaeontology and nuclear physics, CE provides a reasonable characterization of the way scientists behave. The scientists’ assessment of their theories’ success is compatible with the claim that they aim at EA. In addition, their motives for investigating a specific scientific question can be explained satisfactorily on the basis of those statements about the observable world whose viability can be guaranteed without referring to any statements whose truth value lies beyond our grasp according to CE.

CE’s success in the context of palaeontology and nuclear physics directly leads back to the motivational problems related to particle physics. Given the reasons why CE works well in the two very different earlier cases, it is rather straightforward to trace out possible types of scientific theory building where CE is in serious danger to fail. Let us imagine a scientific field that involves unobservable objects but either (a) cannot base the scientific assessment of its theories’ viability on their predictive power or (b) cannot take predictive power as the primary reason for the theories’ relevance. In both cases, the scientific theories would lack the sources of motivation which are present in nuclear physics. If they followed the example of palaeontology, however, and resorted to the quest for truth as a source of motivation, that would directly contradict EA’s role as the aim of science due to the occurrence of unobservable objects. Neither of the two scenarios is farfetched. While scenario (a) might be exemplified by string theory, a theory that thrives without experimental confirmation, scenario (b) precisely resembles the situation in current empirically confirmed elementary particle physics.

5: Norms and Attitudes

Despite its difficult position in the context of contemporary particle physics, CE could still prevail if it were able to provide the basis for alternative motivational strategies. Two potential candidates for fulfilling that task come to mind, which both depend on CE’s literal understanding of scientific theory.

The first strategy, aligned more with the realist stance, is based on CE’s concession that statements about microphysical objects could, in principle, be literally true. Therefore, it might be argued that CE, unlike stronger forms of antirealism, leaves some room for using the literal truth of microphysical statements as a motivational source after all. This line of defence lacks persuasion for a simple reason. Microphysical statements, even if true, could not be understood in terms of additional knowledge about the world since CE denies that scientists can ascertain the truth of scientific statements about unobservable objects to a reasonable extent. Accidental and unknown truth of scientific statements, however, provides a quite unsatisfactory basis for the motivation of scientific inquiry.

The second line of defence lies closer to the home territory of empiricism. It might be argued that CE derives the motivation for theory construction from the quest for EA, just like scientific realism derives it from the quest for the truth about the micro-world. This suggestion may look fairly reasonable at first glance. A closer analysis of its validity requires a more in-depth discussion of some aspects of CE.

EA is based on the totality of all possible empirical evidence and does not directly address the current empirical status quo. As [McMullin 2003] has pointed out, this constitutes a surprisingly ambitious conceptual foundation for an antirealist approach. A scientific
antirealist could raise at least two arguments against the workability and usefulness of EA in van Fraassen’s sense.

(1) It is not clear whether a specific theory that covers all possible empirical evidence exists at all. If new empirical evidence were a never-ending stream of new data that for all times required the creation of ever newer theoretical concepts to be accounted for, no specific theory could be formulated that would satisfy the condition of EA.

(2) EA is no less vulnerable to the pessimistic meta-induction [Laudan 1981] than the concept of the truth of scientific statements. If the pessimistic meta-induction establishes that we must expect our current theories to be proven untrue by future experiments, it equally establishes that we must expect them not to be absolutely empirically adequate. EA thus appears to be nearly as over-ambitious a goal for science as truth. If one is willing to accept the over-ambitious goal of EA, however, why should one criticize the scientific realist for the over-ambitious character of her goal of truth?\(^8\)

Van Fraassen uses a subtle strategy to avoid the cited problems. His formulation of CE involves a delicate shift of the level of discussion. Philosophical analysis of the scientific process can be normative or interpretational. Normative statements prescribe what should or should not be inferred philosophically from the results of scientific inquiry. Interpretational statements define the attitude towards scientific theories that can be imputed to the scientists in accordance with their behaviour. The negative statement which provides the foundation for CE is solidly normative. It asserts what kind of conviction scientific research can NOT justify. Van Fraassen emphasises that empirical evidence can only test a theory’s empirical adequacy. Inference to the truth of scientific statements therefore cannot be justified by the scientific research process.\(^9\) The positive claim of CE, however, is decidedly more modest. Van Fraassen says:

(CE) We are always willing to believe that the theory which best explains the evidence, is empirically adequate. [van Fraassen 1980, p20]

In two respects this statement is weaker than its normative counterpart:

(NCE) We ought always be confident that the theory which best explains the evidence is empirically adequate.

First, (CE) is strictly interpretational and does not make any philosophical claims about the accessibility of the empirically adequate theory. The interpretational nature of its central statement enables CE to exploit the advantages of empiricism over scientific realism despite the absolute quality of the notion of EA. The scientific realist is bound to make her assertions at the normative level since she intends to establish the objective core of current scientific theories. She must assume that current theories tell something substantial about the way the world is and therefore remains chained to the final goal of truth that she attributes to science even when evaluating current scientific theories. This, in the end, makes her vulnerable to arguments like the pessimistic meta-induction. Likewise, if van Fraassen’s claims remained at a normative level, he would face problems very similar to the scientific realist’s; (NCE)

\(^8\) [Kukla 1998] has criticised van Fraassen’s case for the retreat to the endorsement of EA on different grounds. As the present paper focuses on one particular aspect of van Fraassen’s position, Kukla’s line of argument does not enter the present discussion, however.

\(^9\) [van Fraassen 1985] emphasises that this argument relies on the understanding that simplicity, uniformity, predictive power and similar qualities can only support theory acceptance but not the belief in a theory’s truth. Section 2 has made the case that the argument additionally relies on the precondition that a theoretical assessment of underdetermination, which clearly would have the potential to support the belief in a theory’s truth, is not part of the research process.
would immediately run into the problems (1) and (2). His retreat to the interpretational level relieves van Fraassen of the task of defending CE against the objections (1) and (2).

A straightforward interpretational formulation of (NCE):

\[(ICE)\] Scientists always believe that the theory which best explains the evidence is empirically adequate.

would face a different problem, however. It would imply that the scientific process is based on the scientists’ unfounded beliefs about their theories’ future success. In addition to the conceptually unsatisfactory nature of this claim, it would constitute a rather questionable accusation since scientists often clearly do NOT hold the belief expressed in (ICE), even in cases of highly successful and generally accepted theories. Van Fraassen therefore takes a second step back and merely speaks of the scientists’ ‘willingness to believe’. The willingness to believe in EA characterises a specific ‘scientific attitude’ towards accepted theories that is not strong enough to contradict any normative statements about the justification of belief in EA. The claim that scientists are willing to believe in the EA of theories therefore does not accuse them of unfounded beliefs. What the scientist clearly believes in is the ‘approximate empirical adequacy’ of scientific theories to the extent that they fit the evidential status quo within specific error bars. Future empirical data can be expected to reveal the limits of the present theories’ approximate empirical adequacy and to guide the search for new theoretical schemes. (CE) merely implies that natural scientists at each stage of the scientific process try to formulate the theory whose EA is most plausible and test the assumption that EA has been achieved. In this sense scientists are ‘willing to believe’ in the EA of currently accepted scientific theories, even though they must and often do expect those theories to be falsified and superseded later on. EA plays the role of a symbolic endpoint of theory succession that can be aimed at without being within reach. Scientists can follow it like sailors heading north can follow the North Star.

According to CE’s understanding of the scientific process, the scientists’ strategies of justification thus remain based entirely on the current empirical status quo. Scientists build theories in order to describe and predict the observable world as known today. The argumentation at the level of scientific attitude clears the way back from the rigidity of the concept of EA to a self-contained assessment of present scientific theories that does not rely on absolute claims. This is why CE remains fully empiricist in spirit and this is why it evades the problems typically faced by scientific realism.

The last paragraphs imply a clear verdict on the suggestion formulated at the beginning of this section: The attempt to derive CE’s motivational power from EA must fail because CE does not make any normative statements about EA. CE does not establish that our present theories can tell us anything substantial about the empirically adequate theories. Therefore, a central precondition for using EA as a motivational source for the construction of our present theories is not fulfilled. The scientific realist can motivate theory construction based on the claim that present scientific theories tell us something about the true theories but faces the problem of having to explain what precisely it is they can tell. CE does not even

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10 To give one example, throughout the 20th century many physicists doubted the absolute empirical adequacy of the assumption of the pointlike nature of particles though theories based on that assumption were clearly those which best explained the empirical evidence.

11 While the given interpretation of CE is supported by the cited chapter of [van Fraassen 1980] and seems to be the most coherent one over all, it should be noted that it is not univocally supported by van Fraassen’s texts. His equation of theory acceptance and belief in EA in connection with some applications of the concept of theory acceptance suggests an interpretation closer to (ICE) than admitted in the cited work.

12 That is, anything beyond the statement that the empirically adequate theories are empirically similar to our present theories within the currently available experimental context.
claim to provide the basis for assertions about the empirically adequate theories and thereby forsakes EA’s potential role as a source of motivation for theory construction from the start. Thus, the avoidance of normative statements turns out to be decidedly more damaging to CE’s ability to explain theory motivation in particle physics than the retreat from truth to EA. If EA were introduced in the context of a normative version of CE, it could be powerful enough to serve as a motivational basis for science. Just because CE remains at the level of characterising the scientific attitude, the motivational basis for the particle physics research programme lies beyond its reach.

6: A Normative Use of Empirical Adequacy

In the light of the previous arguments, a satisfactory account of scientific motivation requires modifications to the classic position of CE. Any such modification would look more convincing, however, if contemporary particle physics, besides showing the need for it, also weakened the arguments which stand against it from CE’s perspective. Given that CE’s avoidance of positive normative statements has turned out to be the core obstacle to a motivational foundation of particle physics, it would be particularly helpful to find features of particle physics which support the tenability of normative statements.

As argued in section 5, van Fraassen avoids positive normative claims in his formulation of CE in order to be immune against the pessimistic meta-induction (PMI). A closer analysis of the relation between normative statements and PMI once more leads back to the question of underdetermination. First, it is important to note that PMI does not constitute an equally serious philosophical argument in all scientific fields. In a field like palaeontology, where assessments of underdetermination play a crucial role for scientific theory appraisal, the trustworthiness of, let’s say, a new theory of dinosaur posture in view of the fact that the preceding theories have all been refuted, is a genuinely scientific question. In order to be a scientific success, the theory must convince large parts of the scientific community that dinosaurs really moved the way conjectured rather than any other way. This, however, takes the edge off the philosophical threat of PMI as long as the scientific process is deemed functional. Only in the case of scientific fields which do not involve assessments of underdetermination, philosophy has to bear the full weight of PMI by itself. In those cases, the renunciation of normative statements about the current theories’ relation to truth or EA may seem advisable. A normative approach in philosophy of science in this light could be vindicated, however, if the scientific fields in question turned out to contain some kind of assessment of underdetermination after all.

At face value, there seems to be no sign of assessments of underdetermination in particle physics. Underdetermination does not play a more important role for specific theory appraisals in particle physics than in the context of nuclear physics which was discussed in section 4. The following paragraphs will argue though, that there are indications of a subtle implicit assessment of underdetermination whose contours become increasingly visible in the context of contemporary fundamental physics.

In section 3, four points were listed to characterize the marginalisation of the phenomena. A fifth point can be added that is of interest in the present context:

5: In contemporary particle physics, theory has replaced experiment as the primary driving force of scientific progress. In earlier microphysics, experiments typically guided the evolution of scientific theories by providing new discoveries. The structure of atoms and nuclei, the existence of a large number of new particles, the different types of
nuclear interactions or phenomena like CP-violation were first discovered by experiment and described theoretically later on. After the discovery of the importance of internal symmetries and the formulation and corroboration of the particle physics standard model in the 1960s and 1970s, this balance between theory and experiment shifted. During the last three decades, particle physicists have become accustomed to a scientific environment where theory building is mainly guided by the theoretical insufficiencies of the existing theories. New theoretical schemes are not introduced due to empirical refutations of their predecessors but rather in order to solve consistency problems of existing theories or to explain a theoretical feature of existing theories that looks unnatural in the old framework. The resulting new theories predict new empirical phenomena which are then sought to be tested experimentally. The prediction and later discovery of W- and Z-bosons and of higher generation quarks and leptons followed this pattern; the experimental discoveries of the Higgs-boson and supersymmetry are current experimental goals, which would fall into the same category. Experiment thus is reduced to the role of a testing device for already existing particle theories.

The dominant role of theory building in particle physics does not rely on qualitatively new characteristics of science. It is related to the theories’ ability to make successful predictions of new phenomena, which can be found, to various extents, in most scientific fields. The particularly strong showing of this quality in particle physics, however, provides a new basis for approaching the question of underdetermination (see [Dawid 2006]). A research strategy that largely consists in the development of highly elaborate but empirically unconfirmed theories can only make sense if there is reason for having some degree of confidence in those theories’ empirical validity in spite of the lack of empirical confirmation. Such confidence must be based on the implicit assumptions (1) that the empirical world allows for a consistent and explanatory powerful theoretical description at the intended level and (2) that there exists only a very limited number of conceptually satisfactory theoretical schemes which fit the available empirical data but give different predictions with respect to upcoming experimental tests. Otherwise, the chances of finding a predictively successful theory on theoretical grounds would be slim. Support for assumption (2) may stem from the observation that it was difficult to find any satisfactory theoretical solution at all and, indirectly but more importantly, from the confirmed success of earlier theories whose construction was based on arguments of theoretical consistency and coherence. The prime example for a successful theory in particle physics is the standard model whose numerous correct predictions would indeed look like miracles if the theoretical consistency problems solved by the theory allowed many alternative theoretical solutions which would have been scientifically satisfactory as well but would have predicted entirely different new

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13 Examples are the particle physics standard model or string theory. The standard model achieved the renormalizability of strong and weak interactions; String Theory is an attempt to solve the problem of infinities which arise when gravity is unified with point-like particle physics.

14 Examples are grand unified theories and low-energy supersymmetry. Grand unified theories aim at explaining the fact that the three microphysical coupling constants have (approximately) the same value at a certain energy scale; low-energy supersymmetry offers an explanation for the huge scale difference between the electroweak scale and the GUT respectively Planck scale.

15 This should only be taken as a tendency, not as an iron rule. Not all testable properties are predicted univocally by particle theory. The test of proton decay would be one example where experiment still sets the pace and theory follows.

16 Of course one may assume that additional criteria like simplicity or beauty enhance the scientist’s confidence in her theory’s viability. This does not change the basic point, however. The scientist would then have to assume (1) that the empirical world allows for a consistent, simple and beautiful description and (2), again, that there exists only a very limited number of theories which qualify under these criteria.
phenomena. Seen in this light, a pattern of successful theoretical predictions of new phenomena in a scientific field seems to reveal a scarcity of theoretical options that places limitations on scientific underdetermination, which may, in turn, be extrapolated to so far unconfirmed theories in the field. The trust in the viability of concepts like supersymmetry or string theory which is shared by many of these theories’ exponents demonstrates that considerations of that kind play a significant role in particle physics.

What has been said so far suggests a subtle connection between a theory’s power to predict new phenomena correctly and the degree of underdetermination of scientific theory-building at the given point. In this sense, an experiment which tests a theory’s capability to predict new phenomena comes close to being a test of underdetermination. If scientists rely on such indirect assessments of the limitations on underdetermination for developing some degree of confidence in the validity of their new theoretical schemes, however, these considerations may naturally be expected to have a more general motivational aspect as well.

In analogy with the palaeontological case, where the assessment of underdetermination was required by the field’s motivational basis, the indirect assessment of limitations of underdetermination through the appraisal of successful predictions of new phenomena might play a role for providing the motivational foundations for scientific fields where theoretical predictions of new phenomena are abundant.

The motivational mechanism must work in a slightly different way than in the case of palaeontology, though. While the assessment of underdetermination in palaeontology is based entirely on theoretical reasoning, predictions of new phenomena must be confirmed empirically. This restricts their significance with respect to underdetermination since underdetermination by all possible empirical evidence by definition lies beyond the grasp of experimental inquiry and cannot be assessed by experimentally induced statements. A theory’s capability to predict new phenomena correctly therefore can only provide information about the underdetermination of the construction of empirically non-equivalent scientific theories by the currently available data. Consequently, such information can not favour the claim that science aims at truth over the claim that it aims at EA. If sufficiently strong, however, it might strengthen the case for EA and eventually offer a perspective for a normative use of that concept. Scientists may infer from their theories’ strong capability for correctly predicting new phenomena that the degree of underdetermination of theory by experiment is sufficiently limited to justify the assumption that the current theories can provide some kind of knowledge about the empirically adequate theories.

As predictions of new phenomena were always part of the scientific process in physics and other fields of natural science, the conjecture of an indirect motivational role of these incidents, if valid at all, should be expected to apply to many fields of science. In the presence of other, perhaps stronger motivational sources, however, scientific motivation based on predictions of new phenomena would not become crucial for the construal of the scientific process. It assumes a crucial role only in scientific fields like contemporary particle physics, where scientific motivation is threatened by the marginalisation of the phenomena. The fact that the process of the marginalisation of the phenomena in particle physics coincides with a strongly increased importance of theory-based predictions of new phenomena enhances the plausibility of a conception of the scientific process where the latter’s motivational foundation largely depends on the described indirect assessment of underdetermination.

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17 The use of the phrase “entirely different new phenomena” requires some specification. The particle physics standard model does allow empirically non-equivalent modifications and extensions (an example would be theories of dynamical electroweak symmetry breaking). There exists a core of empirical implications, however, which are implied by the basic concepts deployed to solve the crucial conceptual problems the standard model was built to solve, and remain the same in all of these modifications.
A position based on the normative claim that science tells something substantial about the empirically adequate theories strikes a middle ground between ontological scientific realism and empiricism. It agrees with CE in asserting that science aims at making empirically adequate rather than true statements about scientific objects. The position thus is incompatible with ontological scientific realism. On the other hand, the normative use of EA implies a clear distinction from genuine empiricism by justifying the claim that science provides knowledge about something beyond the observable regime. A full construction of a normative conception of science that is based on EA and an exhaustive analysis of the question to what extent such a position could be understood as a modest form of scientific realism lies beyond the scope of the present work. It may just be pointed out that the question of limitations to underdetermination which has played a crucial role in the above discussion seems to offer a number of new starting points for philosophical analysis in the context of modern fundamental physics. [Dawid 2006] argues that limitations to underdetermination could replace full-scale scientific realism in dealing with the ‘miracle’ of the predictive success of science. [Dawid 2005] demonstrates that the reduction of scientific underdetermination plays a particularly important role in string theory. The search for a position in the scientific realism debate that takes into account the motivational situation of particle physics may thus lead to results which form a coherent whole with other philosophical implications of contemporary fundamental physics.

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References


van Fraassen, B. C. 2003: ‘On McMullin’s Appreciation of Realism Concerning the Sciences’, Philosophy of Science 70, p479.