The Issue of Reductionism

A Radical Constructivist Approach to the Philosophy of Physics

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► **Purpose** – To examine the role of reductionism in the theoretical development of modern physics – more specifically, in the quest for a complete unification of physical theory – from the perspective of radical constructivism (RC). ► **Approach** – Some central features of the impact of RC on philosophy of physics are pointed out: its position of scientific relativism, with important implications for the validation of scientific propositions; and the notion of sharing constructed knowledge among individual knowers and its consequences for science teaching. The issue of reductionism is then discussed with regard to (a) the hierarchical explanatory ordering of physical phenomena; (b) the idea of a "theory of everything" (TOE); and (c) some of its implications for the methodology and sociology of science. ► **Findings** – It is argued that the ontological status of the hierarchical structuring inherent in the sought-after TOE will depend on the individual knower's epistemic position concerning the notion of truth in science. In the relativist epistemology of RC, any true/false dichotomy of theories is without meaning. A hierarchical ordering is just one of many possible strategies that may be chosen for the construction of physical theories; and such a strategy may then be considered successful only to the extent that it yields a theory that is viable. ► **Implications** – The paper serves as an illustration of the impact of RC on the ongoing search in physics for a "final theory."
► **Key words** – final theory, epistemology, ontology, philosophy of physics, reductionism, relativism, theory of everything.

Physics – discipline and philosophy

What do we mean by the term *physics*? And what is the interface between what one might call the *discipline* of physics – comprising, in a loose manner of speaking, all the diverse activities that physicists engage in – and the *philosophy* that addresses this discipline?

The Oxford English Dictionary (OED) defines physics as "the science dealing with the properties and interactions of matter and energy." Clearly, this definition covers a wide field: indeed, some have argued that it may be taken, in essence, to contain *all* the natural sciences. This is one vision of *scientific reductionism*, which will be discussed below.

In practice, however, the scope of physics is generally taken to be more narrow. In fact, there is a generally accepted delimitation of this term: it is identified as a set of more or less well-defined sub-disciplines, called *physical theories*. Among these are: classical mechanics and electromagnetism, special and general relativity theory, thermodynamics and statistical mechanics, hydrodynamics and solid-state physics, quantum mechanics and electrodynamics, and high-energy particle physics. In each of them is implicit a description of a certain *domain of phenomena*: the kind of physical objects/systems that the particular theory is designed to describe (macroscopic matter, molecules and atoms, elementary particles, fields of various kinds, etc.). The theory will then feature a number of relationships, generally referred to as *physical laws*, that govern the behaviour of the objects/systems within the domain. (It may be remarked that these theories all deal, in one way or another, with motions of material bodies and the forces acting on such bodies. This is, in fact, the definition of physics that is commonly offered in text books at the secondary school educational level. It serves to distinguish physics from the other "school sciences," such as chemistry and biology.)

Thus, in the present context, the discipline of physics – essentially delineating what physicists are doing – may be described as follows: it proposes physical laws, and/or explores the consequences of such laws when they are applied to specific physical systems.

And what then characterises the philosophy of physics? Clearly, this can also cover a large area of topics – a recent book, where many such topics are discussed, is that of Lange (2002). Here I will focus on the knowledge of scientific theory, such as can be constructed in physics – in particular, on issues of *epistemology* (the nature and validation of this knowledge) and *ontology* (how it is related to the world, i.e., what it can be said to be "knowledge of"). This will be done from the perspective of radical constructivism (RC).

Radical constructivism and physics

It is a central assertion of RC, as proposed by Glasersfeld (1993, 1995), that any kind of knowledge that an individual person can possess is (and must be) constructed in her own mind, for the purpose of adaptation to some aspect of her experiential world. One implication of this, as I see it, is that RC supports the position of *scientific relativism* with respect to both epistemology and ontology: any proposition of scientific knowledge must be constructed by individual cognising subjects; no such proposition can be identified as being *objectively true*, in the sense of describing "correctly" some aspect of the world independently of the person who possesses this knowledge (the knower). On the contrary, the truth value of any scientific proposition can only be defined relative to some given set of criteria, which the knower may then choose to accept or reject. This may be contrasted with the epistemic and ontological position known as *scientific realism*, which asserts that it is possible to obtain objectively true knowledge of the world we experience – or, at least, to obtain knowledge that approaches this state of objective truth. (For a more detailed examination of the issue of relativism vs. realism, with a discussion of how RC impacts on ontology, see Quale 2007a.)

As is well known, this relativist viewpoint inherent in RC has generated considerable controversy – in particular, within the fields of science education and philosophy of science. For instance, it has been accused of being *logically inconsistent*. The inconsistency derives (it is claimed) from one version of the classical paradox associated with *self-reference*. In a simplified formulation, it may be expressed something like this: Consider the statement "there is no such thing as true knowledge." If this statement is true, then it by definition expresses true knowledge, which contradicts the content of the statement; hence it must be false. Thus (the critics will argue) the basic claim of RC – that there is no objectively true knowledge – reflects back on and undermines RC itself, since it denies that the theory can be right. However, I would claim that this criticism (of paradoxical self-reference) misses the point: namely, that RC makes no claim to represent "truth," either in a logical or an ontological sense. In other words, it is *not* a logical proposition, that is deduced from an axiomatic base; more importantly, it does *not* pretend to give an objectively true representation of "the way the world is." In other words, RC is not a theory that purports to present a correct epistemology and ontology, which can then be applied to its own world view. It would be more appropriate to say that RC *recommends itself* to the individual knower as a possible epistemic and ontological approach that she may find useful to her in her quest for knowledge. However, the actual adoption of such a relativist approach is then up to the knower: she may choose to do so, if she feels that it resonates well with her own thinking. It may be remarked that this can lead to somewhat "asymmetric" discussions: the realist will claim that her position is objectively right, and that of the relativist is objectively wrong, and challenge the relativist to convince her otherwise; while the relativist will say, not that the realist is wrong, but that there is no such thing as being "objectively right" here – both positions are equally tenable, from a logical and cognitive point of view, but she (the relativist) happens to prefer the one she has chosen.[1]

It may be noted that RC has, on several occasions, been employed to address various issues in natural science – notably in physics, see e.g., Duit, Goldberg, & Niedderer (1992) and Riegler (2001). In the present article, the issue of *reductionism* (which is not explicitly addressed in these references) will be examined. But first, some general preliminaries.

The position of RC, as it pertains to issues of physics, may be briefly summarised as follows: A physical theory, considered as an item of knowledge, is a *model* of some domain of physical phenomena. This model is then constructed by the knower in order to gain understanding (and even control) of these phenomena. Note that the theory is regarded as an ordered scheme that the knower *chooses to impose* on her experiential world (the phenomena); there is no conception of a pre-existing order lying out there, residing in the phenomena and waiting to be discovered by the physicists. In other words, the world of experienced phenomena is taken to be intrinsically *amorphous*, i.e., to possess no immanent structure of its own. A physical theory that describes (some part of) the world will then be *viable* for the knower, if it: (i) yields predictions that agree with observation, and (ii) fits in with the ontological preferences of the knower.

Note that the second requirement above, describing the notion of viability, is essential. As I understand it, RC accepts what is generally known as the Duhem thesis,[2] which asserts that any theoretical model will be highly *underdetermined* by observation; in other words, it will always be possible to fit many different theories to any given set of observed data. Thus, for instance, we may consider the doctrine of *creationism*, which claims that the biblical account of the origin of the physical world and of humankind, as given in the Book of Genesis, is essentially the correct description – or at least, more correct than present-day scientific theories of physical cosmology and evolutionary biology. It should be clearly understood that this doctrine cannot be disproved by observational evidence. (For instance, the well-known "Adam's navel" hypothesis, proposed in the late 19th century, argued that God did indeed create the world some 6000 years ago, as described in the Bible, but then included in His creation all the discovered fossil material that shows evidence of a much longer time scale – presumably so that He could test our faith…) However, one observes that the *ontological presumptions* of creationism, featuring a Divine Creator and the notion of Intelligent Design as a valid explanatory principle for natural phenomena, are manifestly rejected by the majority of scientists today, as being extraneous and inappropriate to the generally accepted methodology of modern science.

Two objections that are often raised against RC, may deserve a brief comment.

First: How can an amorphous world (of experienced phenomena) be described in a meaningful way by an ordered scheme (a physical theory)? Must there not be some order existing there in the first place for the theory to "capture" in its description? The answer is that there is nothing that logically forbids one from imposing an ordered structure (chosen by personal preference) upon material that is initially unstructured – this is, in fact, something we find in many other areas of our life. As an example, consider the set of all possible musical notes and musical instruments. There is no initial order to be found in this set; but a composer may impose a particular organisation on it and thus produce a musical score – say, a symphony. Here there is indeed an order (the structure of the score); however, this order is devised by the composer, not something that is inherent in the notes and instruments, waiting for the composer to discover it. It may be noted that this example offers an *analogy*, which illustrates one particular activity (constructing a scientific theory) by drawing lines of association with another activity (composing a piece of music); thus it is not claimed that the two activities are "the same" – i.e., identical in all respects.[3] In the present context, the example serves to demonstrate that it is not necessary to assume, on logical grounds, that a scientific theory (i.e., a structured scientific description of a set of experienced phenomena) must reflect an underlying structure in the described phenomena. Of course, whether such an underlying structure is actually there is another matter: a realist epistemic position would assume so, while a relativist (such as that of RC) would reject this assumption.

Second: If scientific knowledge is indeed constructed individually by the knower, how can it be *shared* between scientists, or indeed *taught* by a teacher to her students – how can we know whether they share the same knowledge? This issue is examined in some detail elsewhere (Quale 2007b); the conclusions offered there may be briefly summarised as follows.

Solipsism vs. pluralism

RC accepts,[4] as an ontological premise, that our experiential world is a *shared resource* – this point is discussed and argued in Quale (2007b). In other words: the world is there for each of us to act on, and to interact with each other in. The alternative would be to assume that each one of us constructs our world according to personal whim, uninfluenced by external factors – a worldview known as *solipsism*. It should be noted that this view is *logically unassailable*: I can in fact have no guarantee that the world I perceive around me, including other people that I interact with, is not just "in my own head," a figment of my imagination. However, it is also *existentially irrelevant*: it simply does not reflect the way I experience the world around me, and so I choose to disregard this possibility in the conduct of my life. (Indeed, to do otherwise would in general be considered a sign of mental aberration.) This highlights the crucial distinction that must be made between what might be called the *epistemic* and *ontological* aspects of solipsism – a point that has also been emphasised by Riegler (2001: 1): radical constructivists accept epistemic solipsism, in the sense that all knowledge is (and must be) constructed in the mind of the individual knower; however, they reject ontological solipsism, which holds that nothing exists outside our individual minds, since this would make the very notion of knowledge meaningless.

This bears on the famous dictum of Feyerabend (1978) that "anything goes…" – a statement that is often read as implying that all knowledge is equally valid, and hence as an invitation to solipsism. However, it may also be given a quite different interpretation: namely, that science is a complex and difficult subject matter to deal with, and that one should therefore feel free to try any and all approaches that may seem promising in order to generate scientific knowledge; *but* then with the explicit understanding that many (perhaps most) such attempts will not in fact succeed. In other words, do not be dogmatic about what is, or is not, permissible in the activity of scientific research – feel free to pursue your own ideas; *but* be then prepared to find that this may not lead anywhere. (Indeed, later statements by Feyerabend seem to indicate that such an interpretation would be more in line with what he really meant: it may be read as a plea for *methodological pluralism* – an attitude that resonates well with his own designation of himself as an "epistemological anarchist.") In fact, one may well argue that it is precisely this sort of irreverent attitude that can lead to major breakthroughs in the evolution of science: it prevents science from becoming too set in its ways, and too complacent about having found the one and only "true way" to conduct research.

Knowledge sharing

Knowledge can be shared between people – say, between teacher and students – to the extent that they can interact and communicate in a *common language*. In the case of scientific knowledge, this means not only that they speak the same vernacular (say, English). They must also have acquired the use of a common vocabulary of scientific terms – indeed, the learning of such a vocabulary, and the training in how to use it, constitute a major part of the education of science students. Within the framework of this common language they can then communicate with each other and come to agree that they share some particular item of knowledge. But the knower cannot know for certain that this knowledge is *the same* for all the participants: it is not possible for her to inspect the other person's mind in order to ascertain whether that person understands it the same way that she understands it. Indeed, as any teacher can testify, she may well discover later that her students did not "get it right" after all. In other words, people can share their knowledge, only in so far as *they can agree that they share it* – i.e., to the extent that their actions with respect to this knowledge are "…compatible; in a given situation neither reacts in a way that the other could not expect" (Glasersfeld 1993). In other words: they share it until (possibly) something occurs in the interaction between them, which leads them to discover that they do not share it after all!

This indicates that science should not be taught in the traditional mode of "telling the students the facts about how the world is made up." Rather, it should be taught in a *narrative* mode, i.e., told as a *story* describing the scientific model of the world: how it is constructed, how it works, and why we like it. This conception of narration as a vehicle for science teaching suggests that the evolution of scientific knowledge should be regarded and presented (in science education, at least) as a *historical process*, describable in much the same categories as (say) art history, or political history. Thus, the teaching of science may be regarded as the act of demonstrating the rules of science, and inviting the students to "play the game" – i.e., to investigate how the story can deliver a viable description of many observable phenomena. However, it should be emphasised that this approach does *not* require the epistemic assumption of scientific realism: that science aspires to find an objectively true description of the natural world. Rather, I maintain that RC will advocate a pragmatic approach, where the rules of science are presented as having been chosen by scientists for the purpose of constructing viable knowledge about certain phenomena observed in the world, designed to answer certain questions that scientists like to ask about these phenomena – and then justified only by whatever success these answers may yield. For more details, see Quale (2007b).

The issue of reductionism

Now, let us examine one particular theoretical approach that illustrates the relativism inherent in RC: namely, *reductionism*.

The term "reductionism" is described in the Encyclopedia Britannica in very general terms, as:

> "a view that asserts that entities of a given kind are collections or combinations of entities of a simpler or more basic kind […or that] expressions denoting such entities are definable in terms of expressions denoting the more basic entities."

Similarly, the Oxford English Dictionary defines it as:

> "the principle of analysing complex things into simple constituents [… or…] the doctrine that a system can be fully understood in terms of its isolated parts, or an idea in terms of simple concepts."

In modern (post-Newtonian) European philosophy of science, this notion goes back at least to the Vienna Circle philosophers.[5] One major concern of this group – and of many other philosophers of science in later years – was to clarify the cognitive function of language: the goal was to establish a reliable language in which one could formulate scientific propositions and consider their status as meaningful descriptions of the world.

Another important historical reference in this context is the philosopher of science, Ernest Nagel, who proposed in his book *The Structure of Science* (1961) a formalised scheme of reductionism that he called a "bridge model." The idea was to connect two scientific theories S_p and S_s (generally denoted as the *primary* and *secondary* science), by means of certain "bridge laws," in such a way that all laws and propositions of S_s appeared as just particular manifestations of laws and propositions of S_p. Thus the reduced (secondary) theory S_s is logically derivable from the reducing (primary) theory S_p; in other words, the scientific theory S_s was shown to appear as just one particular instance of the more general theory S_p. Nagel discusses several examples of this taken from physics: for instance, classical thermodynamics is demonstrated to be reducible to a special case of statistical (Newtonian) mechanics; and geometrical optics is similarly reduced to Maxwellian electrodynamics. However, this approach came under criticism from many philosophers of science, notably Hilary Putnam (1975), who pointed out that the purported "bridge laws" depended crucially on the way in which the theories were formulated – hence, the status of these laws as *scientific propositions* was not clear. We will get back to this point later.

It may be remarked that the term "reductionism" itself has often been invested with negative connotations in the discourse. For instance, Uebel (2006) raises the question "…[how] can Vienna Circle philosophy be absolved of reductionism?" Indeed, many authors have expressed criticism of the idea that complex entities can be meaningfully reduced into their simpler parts. For instance, it was pointed out by Quine (1953) that scientific propositions do not occur singly, but always as part of a collection of propositions, which together form a theory; and therefore such a proposition cannot be tested in isolation but needs to be considered against the background of the rest of the theory. Thus, if a theoretical structure is reduced into simpler components, it is not possible to assess the scientific meaning of these components independently of each other.

We remark that Quine uses the term "reductionism" in a very general linguistic sense, as implying that any meaningful statement must get its meaning from some logical construction of terms that refers exclusively to immediate experience. As such, it has a wide field of application in fields as diverse as mathematics and the natural sciences, linguistics, psychology, philosophy and theology. In the context of science, one may also distinguish between different aspects of reductionism: thus one finds in the literature notions such as *conceptual reductionism* (can the concepts of one science be taken to be just special manifestations of those of another, supposedly more "fundamental," science?), *ontological reductionism* (can, for instance, biological entities be exhaustively described as nothing more than collections of the fundamental particles that are at the basis of theoretical physics?), and *law reductionism* (can the laws of one science be taken to constitute nothing but special cases of the laws of another? Cf. Nagel 2007 and Williams 2007). We return to this typology below, and consider it in the perspective that is offered by RC.

It is not within the scope of this paper to address in full generality the notion of reductionism. Here, I shall discuss this notion as it appears in the development of modern physical theory: specifically, in the search for a *unified theory* of physics.

In this restricted context, reductionism may be defined (somewhat loosely) as the idea that one physical phenomenon *A* can be subsumed under another physical phenomenon *B* – in other words, that *A* constitutes (or may be described as, or reduces to) a particular manifestation of *B*. It then follows that, if we know the laws governing *B*, we need not assume in addition the laws governing *A*, since *A* is already "contained" in *B*. Thus, for instance, electric and magnetic forces are commonly described in physics as different manifestations of an entity known as the electromagnetic field. One consequence of this is that the force between two electric charges, as given by Coulomb's law, can be derived from the Maxwellian equations that govern this field; and hence this force law need not be postulated separately in addition to the electromagnetic field equations.

Regarded as a program for physical research, reductionism can be viewed in at least two different aspects given below.

Towards a final theory?

The first aspect addresses the methodology of investigation. When examining a new phenomenon, it is natural to try to connect it with other phenomena that are better understood. In fact, it has traditionally been a fundamental ontological assumption, guiding research in the natural sciences, that "Nature is unified," i.e., that the myriad of individual laws that seem to govern natural phenomena must be interconnected in some way. Indeed, it may be argued that the opposite view – i.e., that each observable phenomenon obeys its own laws, which are totally isolated from those of other phenomena – would reduce science to merely a random listing of unrelated propositions.

The goal is then to impose some sort of connective *order* on the laws of science. One possible such ordering scheme is that of a *hierarchy*, where some laws can be derived from others. In the generic example described above, one would say that *B* lies above *A* in the hierarchy, in the sense that the laws governing *A* are derivable as special instances of the laws governing *B*. Similarly, one might hypothesise some third phenomenon *C* that lies above *B* in the hierarchy, so that the laws governing *B* – and hence, by extension, also those governing *A* – are derivable from the laws governing *C*; and so forth. In this way, the burden of justifying individual scientific laws is "passed upwards," so to speak, in the hierarchy.

(It may be noted that the hierarchy is not the only possible scheme for ordering physical laws. For instance, two alternative approaches that attracted a lot of attention and research effort in the 1960s and '70s were the bootstrapping principle and the S-matrix theory, both strongly championed by Geoffrey Chew and his collaborators – see e.g., Chew (1962). However, these efforts have been largely abandoned in recent years.)

Some obvious questions now arise: Where does the hierarchy stop – that is to say, how far up can it be extended? (In fact, one might well ask: Does it have to stop at all, or is it, in principle, possible to extend the hierarchy upwards indefinitely?) More particularly, is it possible to establish one "super-theory" that lies at the top of the hierarchy, so that *all* scientific laws in principle can be derived (either directly, or through intermediary levels) from this theory? This is, in fact, the goal of the Theory Of Everything program of physics, as, e.g., described in Steven Weinberg's (1993) book *Dreams of a Final Theory*.

A massive research effort has been expended on this program in recent years. The goal is to establish the Final Theory of physics by completing the program of *unification* that was started in the 19th century, seeking to bring seemingly different physical phenomena together and display them as being simply different aspects of one unified "super-phenomenon." Thus it was demonstrated early on that the phenomena of electricity, magnetism and light could be described formally as being different manifestations of a single unified entity: the electromagnetic field. Subsequently, other phenomena (the weak and strong nuclear forces) were brought into a corresponding unification with electromagnetism; the hope is that this should be possible to achieve for *all* physical interactions – the final realisation of Albert Einstein's dream of a unified field theory, though in a form very different from that envisaged by him. One might describe this program as aiming for an ultimate reductionism in the discipline of physics: the goal is to arrive at a Theory Of Everything (often referred to in the literature by the acronym TOE) – a set of laws governing one "super-field," which then unifies all the phenomena (forces, fields, particles, etc.) that together make up the entire physical universe.

This is, of course, a truly grand vision – and note that it does not necessarily stop at the discipline of physics. It is not unusual, among physicists, to encounter the tacit assumption that *all* disciplines of natural science in the end only deal with phenomena that can be exhaustively described by physical laws. Or, put another way: All science is really physics – an ultimate reductionism for the whole scientific enterprise. Indeed, this high-handed attitude has through the years been a source of irritation for many "non-physical" natural scientists. More of this below.

The question arises: If one should eventually arrive at this TOE, what then? Would this imply that we have reached the end of interesting scientific discovery, in physics at least? In other words, will we then be in possession of the Final Theory that covers all of physics, as envisaged in the title of Weinberg's book (1993)? This issue is in fact being seriously discussed among physicists and other scientists: see, e.g., Horgan's book *The End of Science* (1996). After all, if something is actually lying out there, waiting to be found, it surely cannot be found more than once? In fact, Horgan extends this line of thought to envisage a possible end not only to physics but also to other sciences: biology, informatics, sociology, etc. Here, of course, one may recall that similar apocalyptic visions were also proposed in physics towards the end of the 19th century – I will get back to that point presently.

Gaining the high ground

The second aspect of reductionism may be said to belong more to the sociology of science. It addresses the fact that there is a tendency in some fields of scientific research to try to encroach, so to speak, on each other's territory, i.e., to claim that what other scientists are doing is merely a special application of the theory that defines one's own scientific field of research. Thus, for instance, it is inherent in the TOE program that the various theories of physics (some are given in the incomplete list at the beginning) should all be derivable from this putative "super-theory" that is hypothesised to lie at the top of the hierarchy. To be sure, it must be said that such a derivability is, at the moment, more a matter of principle (and hope) than of practical feasibility: the version of the TOE that is presently attracting the most attention is a theory of fearsome mathematical complexity, featuring so-called *strings* – objects with sizes of the order of 10^{-33} cm, which move and interact in a space of either nine or ten dimensions (depending on which version of the theory one favours, e.g., Greene 2000). The actual connection, i.e., the mathematical deductions that will unambiguously connect this theory to the realm of the rest of physics, is not clear, to say the least. Nevertheless, there is an undeniable status attached to the idea of being situated at the top of the hierarchy of scientific theories – a perception of having gained the ultimate "epistemic high ground," as it were, in the quest for scientific knowledge.

In fact, this kind of encroachment may also be observed to extend across sciences. Thus, as already noted, some physicists will claim that most (if not all) of the other natural sciences – such as chemistry, geology and biology – are in essence just "applications of physics," in the sense that all the phenomena that constitute these sciences can in principle be fully described and understood in terms of physical laws. And once again, while such a description may not be practicable or useful, it still tends to give physics an aura of *precedence* above the other sciences in the epistemic hierarchy – a state of affairs that has naturally generated some resentment in the ranks of the other sciences, directed against what they perceive as "the imperialism of physics" (Earman 1992). In particular, many biologists (e.g., Dupre 1994) will strongly contest the validity of this reductionist scheme, which puts physics in a privileged position as a basis for all other theories; rather, they would claim that biological science has its own independent conceptions and methodology, which can *not* (even in principle) be fully described by physical laws.

The RC position

So, what does RC have to say about the issue of reductionism?

We note that from the perspective of *epistemic realism* it does indeed make sense to ask whether such a hierarchical structuring of scientific theories is *true* – i.e., whether it represents (or can be formulated in such a way as to represent) correctly the manner in which these theories are "really" related. Hence it should be possible, within this epistemology, to find the true answer to the question of whether the strings can *in fact* give us the sought-after TOE – and thus determine whether physics does *in fact* constitute the fundament that underpins all other sciences and can hence provide us with the ultimate true description of Nature: the long sought-after Final Theory. Moreover, for the realist it makes sense to seek the *true* relation between two sciences – say, between biology and physics – and then, with reference to the different aspects of reductionism given above, ask questions such as: Are biological entities in fact nothing more than collections of fundamental particles, as described by physical theory (ontological reductionism)? Are the concepts of biology only special manifestations of the concepts of physics (conceptual reductionism)? Are the laws of biology nothing but special cases of the laws of physics (law reductionism)? Note that these questions are binary (can be answered by "yes" or "no"). Moreover, they need not yield the same *truth value*: for instance, it is in principle possible to argue that ontological reductionism holds (yes, biological entities are totally made up of physical components), while conceptual reductionism may not hold (no, biology may need to establish special concepts that have no relevance in other parts of physics).

On the other hand, RC advocates (as already noted) an epistemology of *relativism*, where such questions are without meaning. Here, reductionism (like any other organising principle) is regarded as a structural scheme, chosen and imposed by scientists for the purpose of achieving some understanding of whatever phenomena are being investigated. In other words, the reductionist approach is in itself perfectly legitimate, whether applied within one science or across sciences. Thus, for instance, physicists should feel perfectly free to try to understand biological science in physical terms – and similarly, of course, biologists may try to describe physical laws in terms of biology, if they so wish. The point is that there are (from the perspective of RC, at least) no absolute rules that proscribe such attempts as being "unscientific"; rather, it is the case that "anything goes," in the Feyerabendian sense described above. In the present context of reductionism, this line of reasoning will then be deemed successful only to the extent that it leads to a scientific theory that is *viable*: i.e., in accordance with observation, and providing satisfactory answers to the questions that are being asked. But even if this should happen, it will *not* imply that there is something objectively "true" or "right" about the approach of reductionism, or the scientific theory that it may lead to. In fact, in the course of time we may well expect new discoveries to come up, raising questions that the reductionist theory cannot answer satisfactorily, and then new theoretical lines of argument will presumably be tried.

When viewed in this relativist perspective of RC, the distinction between the different aspects of reductionism, as described above, becomes less relevant. The binary questions posed above are no longer answerable by a "yes" or "no": there is no truth value associated with the notion of reductionism, whether of the ontological, conceptual or law variety. Thus one may choose to adopt a reductionist approach (in one or more of the aspects noted) in the investigation of a scientific issue, if one feels that this might yield viable answers to the questions that are of interest. But this is then to be considered as a *choice of strategy* for one's scientific research, not as a "right" or "wrong" way to do physics. Thus, for instance, the Nagelian "bridge laws" (as referred to above) appear as one particular strategy of inquiry; they do not represent scientific propositions aiming to describe the world "correctly."

In the concrete case of the TOE, the position taken by RC may be described as follows: *If* it should turn out that such a unified theory of the known fundamental forces – say, as described by strings – can be formulated in a consistent way, and *if* its connection with the rest of physics can be satisfactorily clarified (at the present time those are "big ifs"!), then this would in itself constitute a very interesting result; certainly, the idea of one theory that in principle can explain everything would make for a fascinating and intellectually stimulating story about science to tell the students. However, it would definitely not signal any "end of physics"; at most, it may lead to a closure of this particular reductionist line of inquiry. It is a notable feature of the history of science that in the course of time new lines of investigation have constantly appeared on the scene, sometimes leading in quite unexpected directions. For instance, it was widely assumed in the scientific community towards the end of the 19th century, that all the interesting problems of physics were now more or less under control: all natural phenomena were governed by Newtonian mechanics and Maxwellian electromagnetism, and thus there were essentially no more new fundamental laws of physics to be discovered – all that remained was to make more painstaking observations of concrete physical systems, and more exact measurements of physical quantities (a research program often referred to as "the pursuit of the next decimal digit"[6]). And then, the beginning of the 20th century witnessed the dramatic emergence of quantum mechanics and relativity, and the consequent recasting of the whole science of physics.

From the viewpoint of RC, this transition of physical theory from the classical to the modern conception may be regarded as a shift in *ontological viewpoint*. It was not the case that the "old theories" of mechanics and electromagnetism were suddenly rejected as being incorrect. On the contrary, these theories still retain their position as quantitatively valid descriptions of a very large class of physical phenomena. Moreover, they can be augmented by extra ontological assumptions (for instance, the existence of a *luminiferous aether*) in such a way as to mimic the predictions of the "new theories." In other words, it is in principle possible to stay with the old ontology of 19th century physics, if one should wish. However, the fact is that very few practitioners of science choose to do so; the new ontological assumptions of relativity and quantum mechanics are almost universally preferred by the physicists of today.

Conclusion

In the relativist ontology of RC, reductionism is regarded as one of several possible methodologies that may be adopted by scientists and imposed on the phenomena they are studying in order to make sense of these phenomena. In the context of physics, a consistent deployment of such a reductionist methodology may, or may not, then lead to a viable physical theory – a Theory Of Everything. However, such a theory (if it can be formulated) would not be a Final Theory of physics, signalling an end to interesting physical research. From the perspective of RC, the idea of discovering an objectively true theoretical description of the physical world is without meaning.

Thus RC rejects the alternative position of ontological realism, where reductionism is taken to be a "natural structuring scheme" that will (it is hoped by some) ultimately yield the *correct description* of the way in which Nature is actually organised. In this case, we should then indeed have arrived at the Final Theory of physics, as envisaged by Weinberg (1993), and the looming issue of a possible end of physics, as raised by Horgan (1996).

In a more general perspective, RC takes the following view of the development of physical theory: There are many different ways to construct viable theories that cover any given set of phenomena. In this setting, new observational discoveries and theoretical approaches will frequently lead to a change in the "rules of the game" – i.e., a change in the *ontological preferences* that lie at the basis of the definition of *viable physical knowledge* – which in turn will inspire further research and the construction of new theories. In fact, the viewpoint suggested by RC is that it is precisely this evolution of the criteria of viability that in effect drives the progress of physics.

Notes

1. I am grateful to an anonymous reviewer for pointing out the need to clarify this point.
2. Sometimes referred to in the literature as the Duhem-Quine thesis, see, e.g., Ariew (1984).
3. A detailed discussion of the use of analogic reasoning in science is given elsewhere (Quale 2002).
4. It should be said that this is my interpretation of the theory – it is not universally accepted among constructivists.
5. Cf. Uebel (2006) for a very readable and informative account of the contribution of several Vienna Circle members to the philosophy of science, relevant to the present discussion of reductionism.
6. Cf. http://amasci.com/weird/end.html for a number of quotes illustrating this point.

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