

Uninterpreted Equations and the Structure-Nature Distinction

Ioannis Votsis

University of Bristol

Introduction

Stathis Psillos ((1995), (1999), (2000), (2001a), (2001b)) spearheads the critique of epistemic structural realism (ESR). ESR comes in two flavours, Russellian and Poincaréan-Worrallian. Psillos raises objections to both. In this paper, I evaluate two of Psillos' leading objections against Poincaréan-Worrallian ESR.

Epistemic Structural Realism

Before unsheathing Psillos' objections, I must first explain what epistemic structural realism asserts and why anyone would find it an attractive position to hold. ESR is, simply put, the view that our knowledge of the physical world is at best restricted to structure. In more technical terms, we can only know the world up to isomorphism. The recent interest in ESR was instigated by the publication of John Worrall's (1989), 'Structural Realism: The Best of Both Worlds?'. Worrall (1982; 1989; 1994) traces the position to the work of Henri Poincaré. Although traditionally regarded as a conventionalist, not only with regard to geometry but also physics, many philosophers agree with Worrall that Poincaré was in fact the first epistemic structural realist (see, for example, Grover Maxwell (1968), Jerzy Giedymin (1982), Elie Zahar (1996; 2001), David Stump (1989), Stathis Psillos (1995; 1999), Barry Gower (2000), and Michael Redhead (2001a)).¹

Poincaré was heavily influenced by German idealism and subscribed to the view that the non-phenomenal entities postulated by scientific theories are the Kantian things-in-themselves. Unlike Kant, however, he thought that it is possible to gain indirect knowledge of the things-in-themselves. What is it exactly that he thought we could know about them? Poincaré is unequivocal: "[T]he aim of science is not things themselves, as the dogmatists in their simplicity imagine, but the relations between things; outside those relations there is no reality knowable" ([1905]1952: xxiv). And

again later on in the same book: “The true relations between these real objects are the only reality we can attain” (161). Despite the fact that the term ‘structure’ does not appear in these or other relevant passages, we are entitled to call Poincaré an epistemic structural realist, for structures in their simplest form are just collections of one or more relations.²

The motivation for Poincaré’s structural realism is largely historical. He takes the survival of theoretical relations through theory change as indicative of their having latched onto the world. To support this view, he draws attention to certain historical episodes. Following Poincaré, Worrall (1989) takes the structural similarities between Fresnel’s theory of light and Maxwell’s electromagnetic theory as historical evidence for ESR. He indicates that the structure of Fresnel’s theory, as it is for example expressed through his equations for the relative intensities of reflected and refracted light at the boundary between two transparent media of differing optical densities, was carried over to Maxwell’s theory unscathed. To be precise, one can derive Fresnel’s equations from Maxwell’s theory. Thus, Worrall argues, if we look at theory change solely from the perspective of mathematical structure, the Fresnel-Maxwell case counts as evidence for the essentially cumulative development of science.³ According to both Poincaré and Worrall, Fresnel was completely wrong about the *nature* of light, viz. that light consists of vibrations that are transmitted through an all-pervading medium, the ether. Fresnel was probably right, however, about its *structure*, i.e. that optical effects depend on something or other that vibrates at right angles to the direction of propagation of light.

One of Worrall’s main achievements is that he relates this discussion to the current debate on scientific realism. He argues that a sensible position in the debate needs to take into consideration two warring arguments: the no-miracle argument (NMA) and the pessimistic meta-induction argument (PMI).⁴ In short, PMI holds that since predictively successful scientific theories have eventually been discarded, we have

¹ Grover Maxwell coined the term ‘structural realism’. Stump (1989) does not seem to be aware of the structural realist literature but in effect understands Poincaré as a structural realist.

² See below for a formal definition of structure.

³ Heinrich Hertz’s often quoted comment that ‘Maxwell’s theory is the system of Maxwell’s equations’ is congenial with Worrall and Poincaré’s claim that the essence of a theory is its mathematical structure.

⁴ Worrall credits Poincaré and Duhem with the first formulations of PMI and NMA (1989: 140-2).

inductive evidence that even our current theories, despite their great successes, will also be discarded one day. NMA holds that realism is the *only* view that does not make the predictive success of science a miracle. Worrall offers ESR as a position that underwrites both of these arguments and situates itself midway between constructive empiricism and traditional scientific realism. It underwrites the NMA because it argues that the success of science reflects the fact that we have got the structure of the world right. It underwrites PMI because it concedes that non-structure gets abandoned.

Though Worrall does not explicitly state what he means by ‘structure’ the notion is generally understood in a set-theoretical way.⁵ That is, a structure $S = (U, R)$ is specified by a non-empty set of objects U , i.e. the domain, and a non-empty set of relations R defined on those objects.⁶ To express the epistemic structural realist idea that one does not have any access to the relata, i.e. the objects in U , other than through the relations they stand in, i.e. set R , the notion of ‘abstract structure’ can be drafted in (see Redhead (2001a)). To understand the notion of abstract structure we must first understand what it means for two structures to be isomorphic. A structure $S = (U, R)$ is *isomorphic* to a structure $T = (U', R')$ just in case there is a bijection $\phi: U \rightarrow U'$ such that for all x_1, \dots, x_n in U , (x_1, \dots, x_n) satisfies the relation R_i in U iff $(\phi(x_1), \dots, \phi(x_n))$ satisfies the corresponding relation R_i' in U' . An *abstract structure* Σ is an isomorphism class whose members are all, and only those, structures that are isomorphic to some given structure. The notion of abstract structure comes in handy because to ask whether something has a given abstract structure is to ask whether it has the right number of objects that stand in the right relations. The nature of the objects becomes irrelevant, exactly as the epistemic structural realist requires. It is worth noting that the notion of abstract structure is contrasted with what Redhead calls ‘concrete structure’, a structure that uniquely specifies its domain of objects.

⁵ Against this view, Elaine Landry has recently suggested category theory as a more suitable representational framework.

⁶ The definition of structure sometimes includes a third condition, i.e. a set O of operations on U (which may be empty). This condition is optional because operations are functions and thus can be regarded as special kinds of relations capturable by condition two. A structure may also specify one-place relations, i.e. properties.

The proper way to express the knowledge claims of structural realism, according to Worrall (2000), is through Ramseyfication.⁷ That is, structural claims about the world are expressed through the Ramsey sentence of a successful scientific theory. Suppose sentence Ψ with n theoretical predicates and m observational predicates ($T_1, \dots, T_n; O_1, \dots, O_m$) expresses our theory. To obtain the Ramsey sentence of Ψ we turn its theoretical predicates into bound variables (Φ_1, \dots, Φ_n) and existentially quantify over them leaving the observational predicates intact, viz. $\exists\Phi_1 \dots \exists\Phi_n (\Phi_1, \dots, \Phi_n; O_1, \dots, O_m)$.⁸

The idea of marrying ESR and the Ramsey sentence approach comes from Grover Maxwell who in the 1960's and 1970's worked on reviving Russell's ESR. Indeed, Maxwell thought that Russell's work on ESR had in some respects anticipated the Ramsey sentence approach. Maxwell praises Russell, among other things, for the reconciliation of realism with the verificationist principle. This is achieved, Maxwell claims, through Russell's principle of acquaintance and his distinction between knowledge by acquaintance and knowledge by description. The principle of acquaintance is a close relative of the verificationist principle, for it states that to understand a proposition we must be acquainted with all of its constituents. With some perhaps not so trivial adjustments to the terminology, Maxwell claims that all descriptive terms in a meaningful sentence must refer to 'items' of our acquaintance, i.e. all descriptive terms *must* be observation terms (as opposed to theoretical terms).⁹ Yet realism requires that we have knowledge of items with which we are not acquainted. This is where Russell's knowledge by description comes in, for it allows an object to be known by a list of descriptions – i.e. without our first being acquainted with it. Needless to say Maxwell takes knowledge by description to be the same as knowledge via theory.

It is worth noting the idiosyncratic use of the term 'unobservable' in the structural realist literature. Following Russell, Maxwell urges commitment to the view that "all of the external world including even our own bodies is unobserved and unobservable" (1968: 152). He is thus using the term 'unobservable' in a way that is different from

⁷ I argue below that Ramseyfication is not the only option available to the structural realist.

⁸ This is a schematic way of presenting a Ramsey-sentence. Actual examples follow.

⁹ He thus assumes that the terms 'observation' and 'acquaintance' are co-extensive (1970a: 182).

its use today. Like Russell, he does not discriminate between macro and micro-physical objects. For them, the term ‘unobservable’ denotes the set of all things inhabiting the external, i.e. physical, world. Their claim, of course, is not that our observations have no causal origins in the external world, but rather that what we are directly aware of is ‘wholly in our mind’. This is an indirect realist understanding of our knowledge of the external world. Unless otherwise noted, I will henceforth utilise Russell and Maxwell’s interpretation for the terms ‘observable’ and ‘unobservable’, an interpretation advocated also by Worrall.¹⁰

As I mentioned above, one of Maxwell’s contributions to the debate is the bridge he forges between the Ramsey-sentence approach and structural realism. It is at this point that the utility of the principle of acquaintance and the acquaintance vs. description distinction becomes evident. According to Maxwell, knowledge representation via the Ramsey-sentence approach validates both the principle and the distinction. This is so, because the Ramsey-sentence approach existentially quantifies over all theoretical terms but leaves all observation terms intact. In accordance with Russell’s principle of acquaintance, the ‘items’ that theoretical terms supposedly refer to, unlike the items of observation terms, are not ‘ingredients’ of a proposition. For Russell, this means that sentences expressing such a proposition will not contain a name or descriptive constant that refers directly to the alleged items. Diverging from Russell’s viewpoint, Maxwell argues that there is a sense in which a proposition *refers* to the items that its theoretical terms prescribe. It refers to them indirectly, through “(1) terms whose *direct* referents are items of acquaintance and (2) items of a purely logical nature such as variables, quantifiers and connectives” (1970a: 182-3).

The advantage of employing the Ramsey-sentence approach is that its assertions are restricted to properties of theoretical properties, i.e. it does not uniquely identify the theoretical properties. This *seems* in accord with Maxwell’s view that we do not have epistemic access to the first-order properties of unobservables.¹¹ According to him, we can only know their second or higher order properties, what he calls ‘structural properties’ (1970b: 18). This is supposed to follow from the idea that first-order properties of phenomena, like colours, need not resemble the first-order properties of

¹⁰ This was made clear in personal communication with Worrall.

their causes. But, Maxwell claims, “[w]hat holds of colors must also be true for all of the first order properties that we perceive directly” (19) [original emphasis]. Since, according to Maxwell, “our (Ramseyfied) theories tell us that they [i.e. the first-order properties of unobservables] exist and what some of *their* (second and higher order) properties are”, the Ramsey-sentence presumably makes a perfect match for ESR (19) [original emphasis].

To fully appreciate the marriage between structural realism and the Ramsey-sentence approach, let us consider one of Maxwell’s examples. Suppose that given numerous observations we pronounce the truth of the following sentence: $(\forall x)(\forall y) [(Ax \ \& \ Dx) \supset (\exists y) Cy]$ where A and D are theoretical predicates which stand for ‘is a radium atom’ and ‘radioactively decays’ respectively, and C is an observation predicate which stands for ‘is an audible click in a Geiger counter’. If this sentence is true then its Ramsey-sentence, namely $(\exists \psi) (\exists \phi) (\forall x) (\forall y) [(\psi x \ \& \ \phi x) \supset (\exists y) Cy]$ where ‘ ψ ’ and ‘ ϕ ’ are predicate variables, will also be true. The principle of acquaintance holds that we cannot know sentences like the first one, because they mistakenly include fully interpreted theoretical predicates, i.e. A and D . The Ramsey sentence version circumvents this problem by merely asserting that such properties exist. Maxwell explains that our knowledge of these properties “is by description and, as in all such cases, we refer to them not by predicate constants, but indirectly by means of purely logical terms plus an observation term, in this case, ‘ C ’ ” (1970a: 186-7).

Despite Maxwell’s best intentions to remain faithful, Russell’s version of ESR is not equivalent to the Ramsey-sentence approach. The Ramsey-sentence preserves the logical structure of an actual scientific theory, whereas the Russellian approach, which is an exercise in rational reconstruction, allows us to infer the abstract structure of the external world from the concrete structure of our perceptions. No wonder then that Maxwell remarks in passing that “the Ramsey sentence is *approximately* equivalent to Russell’s contention that we do have knowledge of the structural properties of the unobservable” (1970b: 17) [my emphasis].

¹¹ This is a point I contest below.

Psillos calls the Poincaréan-Worrallian approach the ‘downward path’ to ESR because it is a top-down approach. It takes preservation of the structure of scientific theories as indicative of what is true or approximately true. Psillos contrasts this with the Russellian approach, which he calls the ‘upward path’ to ESR. The Russellian approach is bottom-up in that it relies on perceptual foundations to provide a reconstruction of our non-perceptual knowledge. In spite of these and other differences, both approaches preach the same message, i.e. at most we can know the logico-mathematical properties of the external world.¹²

Finally, it is worth saying a few words about ontic structural realism. Proposed by James Ladyman and subsequently developed in association with Steven French, the ontic structural realist thesis is taken to have two components: 1) the epistemological component outlined above, and 2) an ontological component which holds that all that exists is structure. According to ontic structural realism, all that we know about the world is structure because all that exists is structure. French and Ladyman controversially urge a reconceptualisation of the role of individuals in terms of structures. Their views have attracted a lot of attention, most of it negative.¹³ I will not discuss ontic structural realism any further, as the focus of this paper is the ‘downward path’ to epistemic structural realism.

The Two Objections

Without further ado, here are Psillos’ two objections:

(1) ESR commits us only to uninterpreted equations, but these are not by themselves enough to produce predictions, and, therefore, do not deserve all the epistemic credit (1999: 153-4; 2001a: S21).

Though raised in the context of criticising Worrall’s ESR, the following objection seems to apply to all versions of ESR:

¹² The Russellian approach is explored in Votsis (forthcoming). Maxwell’s view has affinities to both the upward and the downward path to ESR.

¹³ For more on ontic structural realism see the collection of papers in the special volume of *Synthese*, vol. 136.

(2) The structure vs. nature distinction cannot be sustained (1999: 157).¹⁴

Terminological Issues

I must first clarify some terminological issues, which, as we shall shortly see, are the sources of some of the above objections. Psillos does not sufficiently explicate the notion of structure, and, as a consequence, draws some mistaken conclusions about the commitments made by ESR.¹⁵ He employs a number of terms, some of which were introduced by the structural realists themselves, that loosely refer to what the structural realists have in mind but that are also misleading in their own peculiar way. These are: ‘mathematical structure of theories’, ‘the logico-mathematical structure of theories’, ‘mathematical content of theories’, ‘the mathematical form of laws’, ‘mathematical equations’ and ‘uninterpreted mathematical equations’.

The first one, viz. ‘mathematical structure of theories’, may be too narrow. If we take logic as not subsumed under mathematics, then we are leaving out structures specifiable by logic but not by mathematics. For obvious reasons, this problem is remedied by the term ‘the logico-mathematical structure of theories’. Both terms, however, as well as the term ‘mathematical content of theories’ may be too broad in that there is plenty of mathematical machinery which does not play any representative role.¹⁶ Typically, structures taken to represent the physical world are embedded in broader mathematical structures. The excess mathematical structure is obviously not the target of the structural realist’s commitments. Hence, to say that a structural realist is interested in the whole mathematical content of theories is misleading at best.

The next term, ‘the mathematical form of laws’, is also misleading for at least two reasons. One important reason is that the notion of structure should not be restricted to laws. Laws typically express relations between physical entities, properties and relations, but they are not the only theoretical statements that do so. Functions, equations, symmetries, principles, covariance statements, etc., postulate relations between terms that can usually be expressed set-theoretically in the above-mentioned

¹⁴ Similar objections are raised by Ladyman (1998) and van Fraassen (forthcoming).

¹⁵ See also Redhead’s criticism of Psillos (2001b: 345).

¹⁶ See Redhead’s (2001a) for an interesting discussion of so-called ‘surplus structure’, i.e. mathematical structure that has no representative role.

way.¹⁷ Take, for example, the inequality relations of momentum-position, $\Delta p_x \Delta x \geq h/2$, and time-energy, $\Delta E \Delta t \geq h/2$, where $\Delta(z)$ denotes ‘spreads’ of the value of a measurable quantity z , x a position co-ordinate, p_x the momentum at x , E energy, and t time. These are relations between measurable, and hence *broadly construed observable*, quantities. They thus specify structures, just as much as Newton’s inverse-square law and Boyle’s law for gases. For the same reason the last two terms on the above list, ‘mathematical equations’ and ‘uninterpreted mathematical equations’, are problematic since they restrict the applicability of the notion of structure to equations. As a matter of fact, since the structural realist’s epistemic concerns are with relations, theoretical statements expressed in natural language can also qualify as specifying structures so long as they are expressing relations that have logico-mathematical properties. For example, the statement ‘Diamonds are harder than topaz gemstones and topaz gemstones are harder than apatite minerals’ is entailed by Moh’s scale of hardness, and reflects an ordering of minerals that, among other logico-mathematical properties, exhibits the property of transitivity.

The other reason why the term ‘the mathematical form of laws’ is misleading is that ‘mathematical form’ gives the mistaken impression that syntax is all that matters. I take it that the same holds for the last term on our list, viz. ‘uninterpreted mathematical equations’, with particular emphasis on ‘uninterpreted’. This impression is to some extent motivated by Worrall’s alternative name for structural realism, ‘syntactic realism’. Yet, ESR does not urge belief *only* in the syntax – mathematical form/uninterpreted equations – of a theory. It is to the justification of this last claim that I now turn to, a justification that, if successful, tackles Psillos’ first objection.

Objection 1: ESR commits us only to uninterpreted equations, but these are not by themselves enough to produce predictions, and, therefore, do not deserve all the epistemic credit.

Scientific realists, argues Psillos, deny the ESR claim that “*all* of what is retained is empirical content and (uninterpreted) mathematical equations” (1999: 147) [original emphasis]. The reasoning is that “mathematical equations alone – devoid of their

¹⁷ It is worth noting that whether we get to call something ‘law’, ‘principle’, or ‘equation’ is often a

theoretical content – [cannot] give rise to any predictions... [p]redictions require theoretical hypotheses and auxiliary assumptions” (153). Hence, Psillos concludes, uninterpreted mathematical equations cannot be entirely responsible for the success of the scientific theories in which they appear. This claim reflects an objection that Psillos echoes throughout his work.¹⁸

Is the structural realist arguing that uninterpreted equations are entirely responsible for the success of scientific theories? More specifically, is the structural realist arguing that we should believe only in uninterpreted equations? A careful review of the literature reveals that no structural realist ever supported such a view. Even Worrall, the subject of Psillos’ objection, comes close to holding such a view but does not take the plunge. He comes dangerously close, for example, when in arguing that only structure gets preserved through theory change, he asserts that “Fresnel’s equations are taken over completely intact into the superseding theory – reappearing there *newly interpreted* but, as mathematical equations, entirely unchanged” (1996: 160) [my emphasis]. If one looks at the context in which this sentence was uttered, as I will soon be doing, one can ascertain that by ‘newly interpreted’ Worrall is referring to the reinterpretation of these equations under new ontological assumptions. He does not require any other type of reinterpretation and he certainly does not require that the equations be entirely uninterpreted.

If Psillos is referring to the interpretation that assigns values to the terms of an equation, then he has completely misread the structural realist project. This latter type of interpretation links the terms of an equation – or any other logico-mathematically expressible relation for that matter – to our observations, thereby allowing predictions to be made. This in turn makes verification of the equations possible. Take Worrall’s example of Fresnel’s equations: (1) $R/I = \tan(\theta_1 - \theta_2) / \tan(\theta_1 + \theta_2)$, (2) $R'/I' = \sin(\theta_1 - \theta_2) / \sin(\theta_1 + \theta_2)$, (3) $X/I = (2\sin\theta_2 \cdot \cos\theta_1) / (\sin(\theta_1 + \theta_2) \cdot \cos(\theta_1 - \theta_2))$ and (4) $X'/I' = 2\sin\theta_2 \cdot \cos\theta_1 / (\sin(\theta_1 + \theta_2))$, where θ_1 and θ_2 are the angles made by the incident and

historical accident.

¹⁸ For example, earlier in the book he says “it is best not to treat theories as abstract structures, but instead to appeal to the success of *interpreted* scientific theories in order to argue that the kinds posited by them populate the world” (1999: 69). In his (2001a), he repeats: “...in empirical science we should at least seek more than formal structure. Knowing that the world has a certain formal structure... allows no explanation and no prediction of the phenomena” (S21).

refracted beams with the normal to a plane reflecting surface, and I , R , and X represent the amplitudes of vibration of the incident, reflected, and refracted beams respectively; these are the square roots of the intensities of the components polarised (1) in the plane of incidence I^2 , R^2 , and X^2 , and (2) at right angles to the plane of incidence I'^2 , R'^2 , and X'^2 . The interpretations of the *angles* and the *intensities* are indispensable to the successful application of the equations. Each of these interpretations assigns a measurable, and hence *broadly construed observable* (as opposed to theoretical), property to a term. Such a broad construal is afforded by the fact that Russell, Maxwell and Worrall take 'observability' to denote anything that can be sensed. This includes observations of the output of instruments. Reading off the results of instrument measurements is an act of observation, and in this sense the relevant terms should be thought of as broadly construed observational. In the current context, we can measure the angles and intensities of the incident and refracted beams using instruments such as angular translators and photometers.

Worrall does not question the interpretation of terms θ_1 and θ_2 as angles made by the incident and refracted beams, or of terms I^2 , R^2 , and X^2 as the intensities of the components polarised. Questioning these would be tantamount to renouncing one of the most spectacularly successful set of equations proposed in the nineteenth century. It is only the *ontological* interpretation that Worrall specified as being re-interpretable, not anything else. According to Fresnel's ontological interpretation, light consists of vibrations transmitted through an all-pervading medium, the ether. The ontological interpretation affects only the amplitudes I , R , and X which in Fresnel's framework are understood as vibrations of the ether. Notice that one can simply reinterpret these as amplitudes of *some sort of vibration/oscillation* without any loss of predictive power. That is, Worrall questions what kind of thing is vibrating or oscillating: Is it the ether, the electric and magnetic field strengths, or something else? According to him, we should remain agnostic only with regard to what is doing the vibrating, i.e. only with regard to the ontological interpretation of Fresnel's equations. In other words, we hang on to the idea that *something* is doing the vibrating without being able to specify what that something is, beyond the level of the relations it stands in.

Psillos' accusation that the structural realist subscribes only to uninterpreted equations rests on a serious misreading of the ESR position. The structural realist does subscribe to interpreted equations, as the above example illustrates, but distinguishes between interpretations that link the terms to observations from those that do not. The hoped-for outcome is interpreted equations that represent relations between measurable, in a broad sense observable, things. In Worrall's version of ESR this information is represented via the Ramsey-sentence, which preserves the interpretations of observables and only sacrifices the interpretation of purely theoretical terms in the sense that it turns them into existentially quantified variables.

The viability of the Ramsey-sentence approach to ESR is certainly dubious. Worrall and Zahar (2001) attempt to answer some central concerns, especially those related to the Newman objection. I do not find their answers convincing, but I will refrain from addressing them in this paper. Suffice it to remind the reader that epistemic structural realism need not be rendered via the Ramsey-sentence. As I pointed out in the introduction, Russell's brand of ESR differs from the Ramsey-sentence approach. Indeed, I have argued elsewhere (see Votsis (2003; 2004: ch.4)) that the Russellian approach avoids the particular pitfalls the Ramsey-sentence approach falls into.

Objection 2: The structure vs. nature distinction cannot be sustained

One of the weaker features of Worrall's work on ESR concerns the way in which he contrasts structure to other things. Psillos rightly criticises Worrall for not being clear on "what exactly the distinction he wants to draw is" (1999: 155). While Worrall sometimes talks about the structure of a theory versus its theoretical interpretation, this being sanctioned by his advocacy of the Ramsey-sentence approach, at other times he talks about the structure of an entity or process versus its nature. Regrettably, he does not explain exactly what he means by 'nature'.

Psillos begins his critique by noting that the use of the term 'nature' is anachronistic. To talk of 'nature', he says,

...over and above [the] structural description (physical and mathematical) of a causal agent is to hark back to medieval discourse of 'forms' and 'substances'...

[but such] talk has been overthrown by the scientific revolution of the seventeenth century (155-6).

Without a doubt, the term ‘nature’ carries unwanted baggage with it, having been used in numerous philosophical debates for a variety of reasons. What exactly is meant by it in the present context?

Russell, Poincaré, Maxwell, and Worrall all appeal to the term because of the Kantian undertones of their epistemology. The idea is that we do not have direct access to things-in-themselves, or to ‘the nature of things’, since direct access is limited to perceptions or phenomena. Unlike Kantian epistemology, knowledge of things-in-themselves can be had under ESR, yet it is indirect, i.e. mediated through perception, and only of a structural kind.

How can we best express this idea of natures? One approach, *implicit* in Worrall’s work, is to reduce talk about natures to talk about theoretical interpretations. The aim here is to turn the structure vs. nature distinction into the more familiar logical structure vs. theoretical interpretation distinction. The latter, as I have already mentioned, is sanctioned by the Ramsey-sentence approach, which strips a theory’s theoretical terms of their interpretation and leaves the logical structure and observational interpretation intact. Since Ramsey-sentences make assertions about the properties of theoretical properties, the theoretical properties themselves are presumably the unknowable natures.

Similarly, Russell thinks that we can only have knowledge of the logico-mathematical properties of the properties that things-in-the-world possess, i.e. we can only have knowledge of the abstract structure. Demarcated thus, the nature of things-in-the-world is restricted to that part of physical properties whose description goes beyond isomorphism.¹⁹ In other words, we can know *all* physical properties (of any order) up to isomorphism. That this knowledge does not specify everything about the physical properties is a trivial point. ‘Nature’ thus refers to any non-isomorphically specifiable part of physical properties.

¹⁹ Thus ‘nature’ in this context is not restricted to the essential properties of physical objects, but covers accidental ones too.

What I have just said suggests a widening of the rift between Russell and Maxwell. According to Maxwell, the nature of things-in-themselves is restricted to just their first-order properties. Russell's view, by contrast, takes the nature of things-in-the-world to be restricted to that part of physical properties whose description goes beyond isomorphism. Take a second order property of a physical object. For Maxwell this can be wholly knowable, whereas for Russell it can only be knowable up to isomorphic description.

As I pointed out earlier, Maxwell is influenced by Russell's idea that the properties of phenomena need not resemble the properties of their external world causes. However, he mistakenly restricts these properties to first-order properties.²⁰ But, why, we may ask, should second (or higher)-order properties of phenomena necessarily resemble the second (or higher)-order properties of their causes? It is not clear where Maxwell acquired this idea, but it is certainly not a consequence of his accepting the Ramsey-sentence approach. The Ramsey-sentence quantifies over *any* theoretical properties. It thus does not force its advocates to espouse an epistemic distinction between first-order and higher-order theoretical properties. Owing to Maxwell's interpretation, Psillos mistakenly takes the distinction to be the central tenet of epistemic structural realism.²¹

Having looked at the principal way in which structural realists understand the structure vs. nature distinction, let us return to Psillos' critique. The main objection that Psillos raises is that "it is doubtful that [the distinction] is well-motivated" because: (P1) "the nature and structure of an entity form a continuum" and (P2) "the nature of an entity, process, or physical mechanism is no less knowable than its structure." (155).²² Take P1 first. According to Psillos, the nature of a theoretical entity is not distinct from its structure. When scientists talk about the nature of an entity they "talk about the way in which this entity is structured" (155). Indeed,

²⁰ That may be because he thought that Russell held this view.

²¹ For this reason Psillos' objection that ESR cannot justify the claim that the first-order properties and relations of unobservables are unknowable in principle (1999: 156); (2001a: S20-21) is misdirected against the Russellian variety. I deal with this objection in Votsis (forthcoming).

²² Psillos borders on contradiction when, on the one hand, he claims that there is something beyond structure that gets carried over through theory change and, on the other, he argues that the distinction between structure and non-structure cannot be drawn clearly.

Psillos offers as an example the concept of ‘mass’, saying that “by discovering more about the properties of mass [including its structural properties] we discover more about its nature” (156). This is just P2, according to which, knowing the structure of an entity means knowing its nature, and so, presumably, the structure of an entity cannot really be clearly distinguished from its nature.

There are various problems with both P1 and P2. Let us consider problems with P2 first. Despite having criticised the term ‘nature’ as anachronistic, Psillos in the above quotation takes it as signifying all the properties that entities possess. Defined in this way, it is obvious that knowing the (abstract) structure, i.e. the logico-mathematical properties, of an entity just means knowing some properties of that entity, and, hence, something about its nature. Should we decide to understand ‘nature’ as Psillos does, knowing the (abstract) structure of an entity is knowing something about its nature. Even so, the advocates of ESR can still maintain that the nature of an entity cannot be *completely* known since properties of external world entities, according to them, can only be known up to isomorphism. Psillos does not provide any specific arguments to counter this last claim.

Alternatively, we can adopt the Russellian understanding of the term, according to which ‘nature’ simply refers to that part of properties of external world objects which is left out of an isomorphic description. Better yet, we can baptise some new unloaded term and infuse it with Russell’s idea. After all, what is important is what the term denotes. The distinction between structure and non-structure would then express the distinction between the logico-mathematical properties of external world objects on the one hand, and that part of those properties going beyond the logico-mathematical description on the other. In sum, P2 seems groundless and reduces to no more than terminological quibbling.^{23, 24}

²³ Redhead raises a similar point: “Surely part of what we mean by the nature of an entity is the structural property of the relations into which it enters. I don’t at all disagree with this point. But this is really a *semantic red herring*. All that the structural realist needs to claim, on my account, is that part, i.e. the structural part, of the nature of the posited physical entities is all that we can claim to know” (2001b: 346) [my emphasis].

²⁴ The litmus test for the viability of the Russellian structure vs. nature distinction is presumably whether it survives Newman’s objection. I have argued elsewhere (2003) that it does.

What about P1, i.e. the claim that structure and nature form a continuum? Consider what Psillos has to say:

An exhaustive specification of this set of properties and relations leaves nothing left out. Any talk of something else remaining uncaptured when this specification is made is, I think, obscure. I *conclude*, then, that the ‘nature’ of an entity forms a continuum with its ‘structure’ (156-157) [my emphasis].

Suppose for this discussion, that by ‘nature’ we mean what Psillos means, i.e. presumably all the properties possessed by a given entity. First of all, let me reiterate that by ‘structure’ the structural realist means the logico-mathematical properties of physical objects. This means that there could not be a complete overlap between a set so specified and a set that contains *all* properties concerning an entity. That is, the set of logico-mathematical properties of an entity is a proper subset of the set of all its properties. More to the point, from the view that the properties specified by structure and those specified by nature coincide, it does not follow that they form a continuum. A continuum presupposes two distinct and opposite ends that define an interval. One would assume that what Psillos means by a continuum here is that on one end we find structure and on the other end we find nature. The continuum analogy can be used to express the idea of no privileged dividing line, but it is inconsistent with the idea that the extension of the predicate ‘structure of an entity’ is a proper subset of the extension of the predicate ‘nature of an entity’ or even with the idea that the two predicates have the same extension.

To summarise, Psillos is right to criticise Worrall for not being clear on what the structure vs. nature distinction represents. As we have seen, however, the distinction can be drawn more decisively so long as we define ‘nature’ as designating the non-isomorphically specifiable part of the external world.

Conclusion

In reply to Psillos’ objections we can now give the following answers:

(1) ESR does not involve a commitment to uninterpreted equations. Worrall’s version, in particular, involves a commitment to structures (which includes equations), whose

observation terms are fully interpreted and whose theoretical terms are presumably implicitly defined through their logical relations with one another and with the observation terms. This just amounts to the Ramsey-sentence approach to theories. Contrary to Psillos' objection, such structures have the capacity to produce observable predictions. On the basis of this objection, the claim cannot be made that structures do not deserve all the epistemic credit.

(2) Though the distinction between structure and nature is unclear in Worrall's work, the structural realist can appeal to Russell's distinction which is both precise and wards off Psillos' objections. In particular, Psillos' claim that the nature of an entity is no less knowable than its structure cannot be upheld if we adopt the Russellian view that 'nature' just means the non-isomorphically specifiable part of entities. Moreover, Psillos' assertion that the nature and structure of an entity form a continuum is a badly chosen and ineffective metaphor since: a) Russell's definition allows for a crisp distinction between nature and structure, and b) it is inconsistent with the idea that the extension of the predicate 'structure of an entity' is a proper subset of the extension of the predicate 'nature of an entity', or even with the idea that the two predicates have the same extension.

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