EPISTEMIC STRUCTURAL REALISM AND POINCARÉ'S PHILOSOPHY OF SCIENCE

Katherine Brading and Elise Crull

Recent discussions of structuralist approaches to scientific theories have stemmed primarily from John Worrall's "Structural Realism" in which he defends a position (since characterized "epistemic structural realism") whose historical roots he attributes to Poincaré. In the renewed debate inspired by Worrall, it is thus not uncommon to find Poincaré's name associated with various structuralist positions. However, Poincaré's structuralism is deeply entwined with neo-Kantianism and the roles of convention and objectivity within science. In this article we explore the nature of these dependencies. What emerges is not only a clearer picture of Poincaré's position regarding structuralism but also two arguments for versions of epistemic structuralism different in kind from that of Worrall.

1. Introduction

In what has become a seminal paper in the contemporary literature on scientific realism, Worrall (1989) offers a middle ground for those who feel the realist pull of the "no-miracles" intuition while recognizing the antirealist thrust of arguments based on the pessimistic metainduction. Following Ladyman's (1998) distinction between ontic and epistemic approaches, Worrall's position has been further clarified and dubbed epistemic structural realism (ESR). In his work, Worrall appeals to Poincaré as a historical source for his position. We

Contact Katherine Brading at Department of Philosophy, University of Notre Dame, Notre Dame, IN 46556 (kbrading@nd.edu). Contact Elise Crull at Department of Philosophy, The City College of New York, New York, NY 10031 (ecrull@ccny.cuny.edu).

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argue that the ways in which Poincaré's own position differs from that of contemporary ESR turn out to be highly significant.

We begin by offering a reading of Poincaré's epistemology that acknowledges his neo-Kantian commitments (see sec. 2). These commitments should be taken into account when evaluating the epistemic aspect of Poincaré's alleged ESR. Furthermore, these neo-Kantian commitments lead to an argument for structuralism very different from any found in the contemporary scientific structuralism literature, as a result of which Poincaré's structuralism is of a different kind from that advocated by Worrall. Moreover, if this neo-Kantian reading of Poincaré is accepted, then an obvious consequence is that Poincaré's realism differs from the scientific realism of the contemporary debate in which Worrall is engaged, precisely in virtue of this neo-Kantian framework.

But even should one take exception to our preferred neo-Kantian reading of Poincaré's epistemology, both Poincaré's conventionalism and his analysis of objectivity must be taken into consideration when interpreting his realism (see sec. 3). We show that these considerations—quite apart from any neo-Kantian commitments—themselves lead to a second argument for structuralism differing importantly from Worrall's ESR.

In section 4, we turn our attention explicitly to Worrall. There we provide context for his invocation of Poincaré and how exactly he takes this earlier philosophy to be a precursor to his own approach. In describing Worrall's argument for structuralism (the third argument of this kind presented in this article), one notices nontrivial differences not only in scope but also in motivation (e.g., contingency on the history of scientific theories). We end (sec. 5) by bringing the analyses of Poincaré's philosophy of science generated in earlier sections of the article to bear on the contemporary structuralism debate.

Thus, the goals of this article are situated on two levels: to provide a more nuanced reading of Poincaré's philosophy of science in and of itself and to apply this reading to contemporary accounts of structuralism. This application not only corrects the historical narrative generated by contemporary structuralists but furthermore introduces two novel arguments for potentially stronger structuralist stances—those actually found, we claim, in Poincaré.

2. Poincaré's Neo-Kantian Epistemology

There is no doubt about the appropriateness of labeling Poincaré's position as epistemic in some sense, for in all of his popular works he stresses that which is knowable. More specifically, he is concerned repeatedly with that which is knowable by us—with the particular faculties we have qua human beings. In this section we briefly review his philosophy of mathematics and use this to highlight the roles of synthetic a priori intuition in his philosophy of mechanics and mathematical physics. We argue that this neo-Kantian aspect of Poincaré's philosophy of science has significant consequences for our understanding of the epistemic character of his position.

2.1. Mathematics and the Roles of A Priori Intuition

We begin with arithmetic and proceed to geometry; in the latter we largely follow Folina (1992). Our goal is to move from this background to the cases of mechanics and mathematical physics (see sec. 2.2). Like Kant, Poincaré grounded arithmetic in synthetic a priori intuition. Poincaré argues that "indefinite repetition of the same act," and thus reasoning "by recurrence," is essential to arithmetical reasoning, allowing us to pass from particular results to general theorems. He argues that this rule of reasoning by recurrence is obtained neither from experience nor from logic (it does not follow from the principle of noncontradiction) but is a synthetic a priori intuition. He writes: "This rule, inaccessible to analytical proof and to experiment, is the exact type of the a priori synthetic intuition" (1902/1952, 12–13). He goes on: "The mind has a direct intuition of this power, and experiment can only be for it an opportunity of using it, and thereby of becoming conscious of it" (13). In other words, through using the rule, we become aware that we have this intuition.

Poincaré also grounded geometry in synthetic a priori intuition, but here he made an important departure from Kant. In *Science and Hypothesis*, Poincaré constructs the mathematical continuum in two steps, each of which makes use of the arithmetical synthetic a priori intuition of "indefinite repetition of the same act" mentioned above. However, in chapter 3 of *Last Essays*, Poincaré is explicit that we have an intuition of the spatial continuum that is independent of our arithmetical intuition. He writes:

> I shall conclude that there is in all of us an intuitive notion of the continuum of any number of dimensions whatever because we possess the capacity to construct a physical and mathematical continuum; and that this capacity exists in us before any experience because, without it, experience properly speaking would be impossible and would be reduced to brute sensations, unsuitable for any organization; and because this intuition is merely the awareness that we possess this faculty. And yet this faculty could be used in different ways; it could enable us to construct a space of four just as well as a space of three dimensions. It is the exterior world, it is experience which induces us to make use of it in one sense rather than in the other. (Poincaré 1913/1963, 44)

Poincaré maintains that metrical and projective properties are not part of the intuition that grounds our ability to construct space. Rather than a geometrical intuition (alongside the arithmetical), we have a more general spatial intuition. Thus, Poincaré differs from Kant in maintaining that the dimensionality of space is not synthetic a priori. Folina argues, successfully in our opinion, that according to Poincaré this is because "it is possible to construct viable empirical theories based upon the hypothesis that space is, for example, four-dimensional" (Folina 1992, 36), where "viable" means "viable for us." This connects directly with Poincaré's famous conventionalism concerning the axioms of physical geometry: when Poincaré says that "one geometry cannot be more true than another; it can only be more convenient" (1902/1952, 50), this is because one need not use Euclidean geometry in order to describe the empirical world as we experience it.

In both mathematics and science, Poincaré focuses on what we can know—that is, what is knowable by us, as finite beings, with our intuitive faculties. Folina argues that in the case of arithmetic, the significance of the synthetic a priori status is that we cannot build a "nonstandard" arithmetic—or indeed any formal system—without these principles. Similarly, she says, in the case of geometry (or rather, spatial continuity): the significance is that any account of the world as we experience it will necessarily presuppose the continuity of space. She urges that the relationship of mathematics to experience is crucial to understanding Poincaré's philosophy of mathematics: "Mathematics, like any science, must seek after truth. And truth means more than mere consistency. In mathematics it means (on the Poincaré view) that the axioms cohere with our intuitions, that is, with the form of experience" (Folina 1992, 114). As we will see again later, the notion of truth for Poincaré has the special meaning of applying to intersubjective agreement regarding experiential data, and this importantly qualifies the sense in which he is read as a realist.

2.2. Empirical Science and the Roles of A Priori Intuition

Both arithmetical and spatial intuitions are indispensable for empirical science. In the above quotation from *Last Essays*, Poincaré states that the very possibility of our experience of the world as containing empirical objects depends on spatial intuition when he writes, "this capacity exists in us before any experience because, without it, experience properly speaking would be impossible and would be reduced to brute sensations, unsuitable for any organization." In other words, spatial intuition is that through which our sensations are constituted into our experiences of physical objects; objects that endure through space and time.

But the role of a priori intuition in empirical science extends beyond this, or so we will argue. This is because a science of empirical objects goes beyond mere experience of objects: we must form generalizations over these objects, and our ability to form these generalizations is itself grounded in a priori intuition. In *Science and Hypothesis* part 1, chapter 2, Poincaré asserts that the business of science concerns generalizations—to move from premises to conclusions that are "in a sense more general than the premisses [*sic*]" (Poincaré 1902/1952, 4). His position may be summed up by his own slogan: "There is no science but the science of the general" (4). Granting this, we can ask first about the nature of this generalization and then about what grounds our ability to form such generalizations.

Poincaré distinguishes between mathematics and the physical sciences in the following relevant respect. He highlights the similarity between reasoning by recurrence in arithmetic and by induction in physical science and then points out that induction in the physical sciences is uncertain, whereas reasoning by recurrence is not (Poincaré 1902/1952, 13). The reason he gives is that induction depends for its success on "an order which is external to us," whereas proof by recurrence depends for its success on "a property of the mind itself" (13). Poincaré's own writings leave us at this point of distinguishing between the nature of the generalizations found in mathematics and the physical sciences. But with this difference noted, we might still want to ask what grounds our ability to perform inductive reasoning in the physical sciences. We have seen that in mathematics our ability to generalize is grounded in arithmetical intuition. What about the physical sciences? In answering this, it seems to us that a plausible case can be made for three further roles for a priori intuition within Poincaré's philosophy of science.

To make this case, we again find Folina's analysis a helpful place to start. Folina begins with the role of spatial intuition with respect to our experience of physical objects and then moves on to consider generalizations:

> A priori intuition—or the form of experience—is that via which we understand, by our sensory manifold, an experience of a single object enduring through space and time, despite the inevitably incomplete character of experience. It is also that via which we understand certain rules as characterizing infinite, yet determinate, collections. A priori intuition can thus be regarded as a "glossing over" faculty: a faculty which glosses over the incomplete character of both empirical and mathematical experience. It is a procedure whereby we ignore all the elements which could be generated by a rule, and we disregard or "smooth out" the disparate character of perception. (1992, 86)

Folina argues that for Poincaré our ability to "gloss over" and thereby make generalizations lies in a priori intuition (in spatial intuition for empirical generalizations and in arithmetical intuition for mathematical generalizations). The point here is that, in order to form generalizations, we must disregard as irrelevant certain features of the particular objects that we are placing under the generalization. In the case of physical objects it is, according to Folina's reading of Poincaré, our spatial intuition that allows us to do this.

The second place where a priori intuition plays a role is as follows. Disregarding certain features as irrelevant is necessary but not sufficient for us to form a generalization: we require also the concept of indefinite iterability (a concept that, e.g., allows us to repeatedly apply rules). As Folina writes: "Poincaré believed that the concept of indefinite iterability . . . is foundational, not only for arithmetic, but for all systematic thinking; and its epistemological source is synthetic a priori intuition. . . . It underlies all systematic thinking because it underlies our ability to generalize" (1992, 93). In short, our ability to generalize is grounded in arithmetical a priori intuition because this intuition grounds our ability to perform iterations. Thus, arithmetical intuition also plays a crucial role in our ability to generalize with respect to empirical objects.

We will come to the third role for a priori intuition shortly, but first—with the above point in mind—we can return to where Poincaré left us, with the distinction between mathematical reasoning by recurrence and induction in the physical sciences. We saw that the difference lies in the objects that are the subject matter of the generalization. The fallibility of induction lies in the fact that we can make mistakes when we decide which aspects of the particular physical objects to consider irrelevant and which to take into account when forming the generalization. Nevertheless, with this decision made, what grounds our ability to form the generalization is the same in the case of induction as it is for mathematical reasoning by recurrence: it is arithmetical a priori intuition. This is not something that Poincaré says, but it is, we maintain, a plausible answer to a question he left unanswered. The plausibility of this answer is supported by the discussion that Poincaré does offer regarding generalization in physical science, as we now show.

Generalization is involved in physical science at two distinct stages. The first is when the empirical data are organized: we must draw our line through the dots on the page recording our experimental results. The relevant point for our purposes is that this choice goes beyond "mere" generalization: "However timid we may be, there must be interpolation. Experiment only gives us a certain number of isolated points. They must be connected by a continuous line, and this is a true generalisation. But more is done. The curve thus traced will pass between and near the points observed; it will not pass through the points themselves. Thus we are not restricted to generalising our experiment, we correct it. . . . Detached facts cannot therefore satisfy us, and that is why our science must be ordered, or better still, generalised" (Poincaré 1902/1952, 142–43). Thus, the interpolation—the act of drawing a curve to fit the data—is a moment in which Poincaré claims we not only generalize the data but also correct them. This additional feature of empirical generalization (beyond that found in mathematics) arises from the different nature of objects that serve as subject matter for the generalizations and leads to the fallibility of those generalizations.

The second type of generalization takes the results of this first stage (drawing curves through data points) as input in order to generate empirical laws. Hence, the laws are grounded from the start on generalizations. It is these laws, then, that enable us to achieve the desired generality the human mind seeks (Poincaré 1905/1958, 14) and that allow us to make progress in science. In Poincaré's words:

> Who gives us the right of attributing to the principle itself more generality and more precision than to the experiments which have served to demonstrate it? This is asking, if it is legitimate to generalise, as we do every day, empiric data. . . . One thing alone is certain. If this permission were refused to us, science could not exist; or at least would be reduced to a kind of inventory, to the ascertaining of isolated facts. It would not [*sic*] longer be to us of any value, since it could not satisfy our need of order and harmony, and because it would be at the same time incapable of prediction. (1902/1952, 129–30)

In sum, it seems to us that a priori intuition clearly grounds our ability to construct the generalizations that form the very substance of physical theorizing.

There is yet a third role for a priori intuition. It is not just our ability to construct generalizations that is grounded in a priori intuition: our ability to apply the resulting generalizations is similarly grounded. With respect to mathematics, Folina writes: "In order to understand the abstract characterization of a rule, we must understand an arbitrary instance of it. . . . Applying a rule requires that we see that the application possesses the same essential structural properties, or 'shape', as the arbitrary instance given in the schematic characterization of the rule. The aspects which are structural are those which an arbitrary instance possesses. A priori intuition supplies us with the ability to understand what these are" (1992, 87). If this reading of Poincaré is correct, then the conclusion is readily extended beyond mathematics. A physical law is a particular type of rule, and it is a generalization. In order to apply laws (generalizations) to physical objects, we must be able to recognize that the objects instantiate the law. We might go further and insist that to understand a physical law is to be able to recognize an instance of that law. The point is this: insofar as our ability to recognize phenomena as instantiating a law depends on arithmetical or spatial intuition, there is this further role for a priori intuition in Poincaré's philosophy of science.

The generalizations in play here are structural generalizations, as Folina herself emphasizes. That this must be the case follows from her account of a priori intuition. There is, moreover, an additional way to see that the type of generalization at work in physical science must be structural. We discover below that for Poincaré, laws capture the relations between things; to recognize that objects offer an instance of a given law is to recognize that they stand in the relations described by the law. In order to achieve this, we must ignore the nonrelational features of the objects, if any such are presented to us in experience. A priori intuition is therefore not only that which enables us to generalize but also that which enables us to apply the resulting generalizations. By the very nature of what is involved in the construction and application of generalizations, they must concern relations: hence the name *structural* generalizations.

The above reading of Poincaré's epistemology alters how we evaluate the epistemic and realist aspects of Poincaré's philosophy. This reading furthermore leads to an argument for structuralism stemming directly from Poincaré's neo-Kantian commitments that differs from any such argument found in the contemporary scientific structuralism literature. We state this structuralist argument as follows:

Argument 1—From generalization

1. Scientific laws are our generalizations.
2. We are able to generalize due to our arithmetical synthetic a priori intuition.
3. In particular, arithmetical intuition enables us to form structural generalizations.
4. Therefore, scientific laws are structural generalizations.

So far as we are aware, Poincaré never states this argument explicitly. However, he is explicitly committed to the first premise, as various statements in *Science and Hypothesis* make plain (cf. quote above from Poincaré 1902/1952, 129–30). Additionally, Poincaré goes on from that quote to claim, "It is not sufficient merely to observe; we must use our observations, and for that purpose we must generalize" (140). And a few pages further along he defines a good experiment as "that which teaches us something more than an isolated fact. It is that which enables us to predict, and to generalise. Without generalisation, prediction is impossible" (142). A good experiment, in other words, allows us to translate particular instances into laws by generalizing those instances. In this way, laws are themselves generalizations. Moreover, our discussion of Poincaré qua neo-Kantian shows that it is at least plausible he was committed to the remaining premises. Granting these, the conclusion follows readily. Note that Argument 1 presents a kind of structuralism distinct from Worrall's ESR; more on this comparison will be said in section 4, once all three arguments for structuralism have been put on the table.

3. Poincaré's Realism

Whether or not one accepts the above neo-Kantian reading of Poincaré and to what degree, there remain significant differences between Poincaré's realism and realism within the contemporary debate. These differences arise from the role of convention in Poincaré's philosophy of science (treated below in sec. 3.1) and from his account of objectivity (sec. 3.2). These two aspects contribute substantial shading to Poincaré's variety of realism, yielding a second argument for structuralism.

3.1. Conventionalism

Perhaps an obvious place to challenge the interpretation of Poincaré as a scientific realist is through the most famous aspect of his philosophy of science: his conventionalism. However, most discussion on this point focuses on conventionalism in philosophy of geometry specifically; perhaps it is less obvious that conventionalism enters his account of mechanics and physical science as well. In this section, we argue that Poincaré's conventionalism does indeed extend into mechanics and physics and that this fact demands we read the "realist" classification of his philosophy with care. We begin with an overview of his geometric conventionalism, so that we might more easily trace aspects of conventionalism into his description of other scientific arenas.

3.1.1. The Axioms of Geometry as Convention

Poincaré's conventionality with respect to geometry is widely known. Concisely, Poincaré's argument involves reasoning by elimination: he asks, what sort of science is geometry? Can it be considered an a priori science, as Kant insisted? Poincaré answers in the negative, arguing against Kant in part by discussing the equal conceivability of non-Euclidean geometries and in part by appealing to the indemonstrable axioms defining them, to wit—"Every deductive science, and geometry in particular, must rest upon a certain number of indemonstrable axioms" (Poincaré 1902/1952, 35). Poincaré argues that the axioms of other geometries of constant curvature—namely, those of Lobatschevsky and of Riemann—are logically possible and internally coherent, and so their truth cannot be evaluated a priori. This, as was well appreciated by geometers of Poincaré's day, renders Kant's argument for the a prioricity of Euclidean geometry troublesome.

If not a priori, can geometry then be considered empirical science? The answer here is again negative, and Poincaré provides two reasons why. First, he asserts that geometry is unlike empirical sciences in that it cannot be modified in light of new experimental data. Second, geometry is exact and does not rely on approximations the way empirical sciences are constrained to do. Thus, neither is geometry a proper empirical science.

If geometry can be considered neither empirical science nor a priori science, it must be situated on some middle ground. For Poincaré that middle ground is convention: "*The geometrical axioms are therefore neither synthetic a priori intuitions nor experimental facts.* They are conventions. Our choice among all possible conventions is *guided* by experimental facts; but it remains *free*, and is only limited by the necessity of avoiding every contraction, and thus it is that postulates may remain rigorously true even when the experimental laws which have determined their adoption are only approximate. In other words, *the axioms of geometry . . . are only definitions in disguise*" (1902/1952, 50; emphasis original).

3.1.2. Convention in Mechanics and Physics

Already in the author's preface to *Science and Hypothesis*, after stating his thesis about the conventional nature of geometry's axioms, Poincaré tells his readers to expect the following: "In mechanics we shall be led to analogous conclusions, and we shall see that the principles of this science, although more directly based on experience, still share the conventional character of the geometrical postulates" (1902/1952, xxvi). This is a clear statement that his conventionalism extends at least to mechanics, if not farther. Regarding mechanics, Poincaré says that the principles appear to us under two different aspects: "On the one hand, there are truths founded on experiment, and verified approximately as far as almost isolated systems are concerned; on the other hand, there are postulates applicable to the whole of the universe and regarded as rigorously true." It is under this second aspect that principles are seen to rely on convention. Poincaré continues: "If these postulates possess a generality and a certainty which falsify the experimental truths from which they were deduced, it is because they reduce in final analysis to a simple convention that we have a right to make, because we are certain beforehand that no experiment can contradict it" (135–36).

A few pages later Poincaré reaffirms the relationship between principles and conventions as follows: "Principles are conventions and definitions in disguise. They are, however, deduced from experimental laws, and these laws have, so to speak, been erected into principles to which our mind attributes an absolute value" (1902/1952, 138). He goes on to explain the process of elevating laws to the status of principles:

> How can a law become a principle [convention]? It expressed a relation between two real terms, A and B; but it was not rigorously true, it was only approximate. We introduce arbitrarily an intermediate term, C, more or less imaginary, and C is *by definition* that which has with A *exactly* the relation expressed by the law. So our law is decomposed into an absolute and rigorous principle which expresses the relation of A to C, and an approximate experimental and revisable law which expresses the relation of C to B. But it is clear that however far this decomposition may be carried, laws will always remain. (138–39, emphasis original)

In the preceding quotations, we see Poincaré insisting that while convention may no longer be sufficient for describing relations in the case of mechanics as it was in the case of geometry, it is nevertheless still necessary. While conventions in geometry describe an exact relation between objects of the right sort (e.g., different points in space), they are only able to ascribe that relation exactly in virtue of the idealized nature of such objects. Mechanics no longer deals exclusively with idealized objects, and so we will require the application of laws in addition to convention in order to exactly describe relations between the appropriate classes of referents. Consider the example described in the passage above: in order to express a relation between two real objects A and B, one must first relate A to some idealized entity C using whatever convention will yield a "rigorously true" relation under the appropriate mechanical laws. Only then can one consider relations involving some further real object like B—one first applies the principle ("absolute and rigorous") to the relation A–C and then relates C to B via another application of those same laws (noting that the derivation of this second relation is not exact and is revisable).

Poincaré builds his argument for the conventional nature of mechanical principles using the same tactic employed in his argument for the conventionality of geometrical axioms: the principles of mechanics cannot be considered a priori because they are the result of empirical investigation. Yet neither are these principles wholly empirical in nature. Although the principles are originally derived from experiment, we choose to elevate them to a status that no longer admits of empirical verification or falsification. Newton's laws of motion and the law of energy conservation are examples of mechanical laws-cum-principles-cum-conventions, for "being based on experiment, [they] can no longer be invalidated by it" (Poincaré 1902/1952, 127–28). This failure of mechanical principles to qualify as purely a priori or purely empirical leads Poincaré to classify them as convention.

Might one limit the conventional element to geometry and mechanics and keep it from entering the laws of "higher up" natural sciences like physics? Could one not simply stipulate that laws within the natural sciences remain empirical laws, never to be elevated to the status of principles and thereby become tainted by convention? Such a move is indeed consistent with Poincaré's own view. However, it seems to us that it is difficult to make a robust distinction here between mechanics and other areas of mathematical physics. For example, which is the nature of the second law of thermodynamics? Unless a robust distinction can be made that shows how and why the principles of mechanics are conventional whereas the laws appearing elsewhere in mathematical physics are not, some aspect of convention will persist throughout.

Given the nontrivial role convention may play within mechanics and physics, the following question naturally arises: how and in what sense do these conventions come to express real relations? A further story from Poincaré is required at this juncture in order to understand in what sense he might be called a realist. Unfortunately, no such story is offered, and so we are compelled to conclude as follows: Poincaré's conventionalism—if it can be said to comport with any kind of realism at all—certainly cannot be considered to be realist in the same manner as are the positions on offer in the contemporary debate.

3.2. Objectivity

3.2.1. Objectivity and Truth

Poincaré's popular writings are full of terms like "objective reality," "true relations," "real relations," and so on. Much of this talk sounds realist, at least about relations. In the very chapter of *Science and Hypothesis* appealed to by Worrall for his arguments, Poincaré writes (1902/1952, 161): "The true relations between these real objects are the only reality we can attain." However, such statements concerning truth, reality, and objectivity should not be given a straightforward realist interpretation, as Domski (2000) points out. To wit, consider the following excerpt: "If truth be the sole aim worth pursuing, may we hope to attain it? It may well be doubted. Readers of my little book 'Science and Hypothesis' already know what I think about the question. The truth we are permitted to glimpse is not altogether what most men call by that name" (Poincaré 1905/1958, 12).

What does Poincaré mean by truth, then? We alluded briefly to Poincaré's special notion of truth when discussing his neo-Kantianism; let us now add some meat to those bones. A few pages after the above quote from *Value of Science*, we find Poincaré making these considerations:

> Does the harmony the human intelligence thinks it discovers in nature exist outside of this intelligence? No, beyond all doubt, a reality completely independent of the mind which conceives it, sees or feels it, is an impossibility. A world as exterior as that, even if it existed, would for us be forever inaccessible. But what we call objective reality is, in the last analysis, what is common to many thinking beings, and could be common to all; this common part, we shall see, can only be the harmony expressed by mathematical laws. It is this harmony then which is the sole objective reality, the only truth we can attain. (1905/1958, 14)

As this statement makes clear, knowledge of a mind-independent reality is, for Poincaré, impossible. Moreover, objectivity means intersubjective agreement (between human beings or beings with faculties "sufficiently similar" to our own), and truth—as mentioned in section 2—is located within this same intersubjective agreement. Scientific truth and objectivity are what is intersubjectively stable for creatures sufficiently like us, and since mathematical laws express relations between scientific facts, "objective reality" refers to intersubjective agreement concerning these relations.

Similar remarks to those quoted above occur often in the body of Poincaré's works, and this is sufficient to warrant the conclusion that his realism is different from the realism of contemporary philosophers of science. Note that this conclusion holds independently of neo-Kantian considerations.

3.2.2. Objectivity and Structuralism

As just stated, Poincaré's understanding of objectivity is derived from intersubjective agreement. Related to this is Poincaré's account of objective knowledge more generally, which gets us to a further argument for structuralism.

In their book on objectivity, Daston and Galison (2007) claim that the grounds for Poincaré's structuralism lie in his account of objectivity. They distinguish this from the motivation of current structural realists, for which they cite the challenges posed to realism by underdetermination of theory by data and the pessimistic metainduction. They write, "Yet the preoccupations of the late twentieth-century structural realists were not those of the early twentieth-century structural objectivists: the former, like all realists, were primarily interesting in the justification for the claim that science was true, that it correctly described the real features of the world; the latter (including Poincaré) were chiefly concerned with the justification for the claim that science was objective, that it was 'common to all thinking beings' " (261). According to Daston and Galison, the challenge to which Poincaré and others were responding arose from developments in mid-nineteenth-century physiology, psychology, and ethnology that cast doubt on shared experience as the grounds of objectivity. The response was "not to reject scientific objectivity but to deepen it" (259). We can see Poincaré responding to exactly this challenge in chapter 6 of *Value of Science*, entitled "Objectivity of Science." First, he argues for the claim that "what is objective must be common to many minds and consequently transmissible from one to the other" (Poincaré 1905/1958, 345). Then, Poincaré argues: "Sensations are therefore intransmissible, or rather all that is pure quality in them is intransmissible and forever impenetrable. But it is not the same with relations between these sensations. From this point of view, all that is objective is devoid of all quality and is only pure relation" (345).

He argues for this by considering the case of color perception, claiming that we have no means of verifying whether "the sensation I call red is the same as that which my neighbour calls red" (Poincaré 1905/1958, 345). This is an expression of the challenge to objectivity discussed by Daston and Galison. Poincaré concludes: "we must nevertheless admit that nothing is objective which is not transmissible, and consequently that the relations between the sensations can alone have an objective value" (345).

The argument for structuralism that Poincaré gives here can be put into premise-conclusion form as follows, with "communicable" substituted for "transmissible":

Argument 2—From objectivity

1. Objective knowledge is necessarily common to all (i.e., intersubjectively stable).
2. That which is common to all is necessarily communicable.
3. That which is communicable is knowledge of relations only.
4. Therefore, objective knowledge just is knowledge of relations.

This is a very strong conclusion: all objective knowledge (not just scientific knowledge) is necessarily knowledge of relations. It rests on Poincaré's account of the relationship between objectivity and communicability (expressed in premises 1 and 2) and on the empirical discoveries stressed by Daston and Galison (on which premise 3 rests). The argument is independent of the neo-Kantian considerations discussed in section 2.

As applied to science, Poincaré's view that objective knowledge is knowledge of relations finds expression in his famous statement in the preface of *Science and Hypothesis*: "The aim of science is not things in themselves, as the dogmatists in their simplicity imagine, but the relations between things; outside those relations there is no reality knowable" (1902/1952, xxiv). Poincaré is clear that when doing science, our commitment is to relations rather than to the things in themselves. Moreover, this has implications for Poincaré's view of scientific theories. Poincaré describes the role of mathematical physics within physics to be a structural one: in constructing a scientific theory we use mathematics to structure empirically derived scientific facts. Writing about this, he says: "Science is built up of facts, as a house is built of stones; but an accumulation of facts is no more a science than a heap of stones is a house" (141). Employing a different analogy, Poincaré compares the function of mathematical physics to that of a library catalog, where the experimental facts serve as the "books" (144–45). It is the duty of the mathematical physicist to take new data generated by experiment and order them usefully (where "usefully" means that this cataloging process directs us toward the sorts of experiments necessary for supplementing the library with interesting new books). In short, facts must be given structure—this is what it is to do science and to construct scientific theories.

It is here, in his focus on the relations between things and in his structural characterization of theories, that Poincaré comes closest to the structuralism endorsed in contemporary ESR. What Argument 2 highlights, however, is that for Poincaré knowledge of the scientific facts themselves is knowledge of relations. Absent Argument 2, one could adopt Poincaré's structuralist approach to scientific theories without also committing to his view that objective knowledge (including knowledge of scientific facts) is just knowledge of relations. Once Argument 2 is adopted, however, the resulting form of structuralism is deeper and more thoroughgoing than that of the typical contemporary epistemic structural realist: all objective knowledge, including all scientific knowledge, is necessarily knowledge of relations.

We have demonstrated thus far that a careful, context-sensitive reading of Poincaré's philosophy of science can support two arguments for structuralism, and we have shown that each has significantly different scope and motivation from contemporary ESR. Thus, insofar as Poincaré's structuralism arises from Argument 1 or Argument 2, and therefore from neo-Kantian considerations or from considerations of objectivity, respectively, it would be a mistake to equate it with contemporary ESR. We turn now to a third argument for structuralism—that offered by Worrall (1989)—and to the relationship between Poincaré and contemporary ESR.

4. Worrall's ESR in Relation to Poincaré

The central thesis of Worrall's ESR is that we have good reason to believe that the entities in the world exemplify the structures posited by our best scientific theories, but we should be epistemically noncommittal about the nonstructural natures of the entities in question. Worrall writes: "[The structural realist] insists that it is a mistake to think that we can ever 'understand' the *nature* of the basic furniture of the universe" (1989, 122). The position is thus presented as a retreat from full-blown scientific realism that reflects the epistemic modesty appropriate in light of the argument from the pessimistic metainduction. Because the position was developed in this manner, it follows that it is highly contingent on the actual history of science. Worrall says:

> No one should claim a stronger sense of continuity, and hence a stronger version of realism, than is compatible with the historical record. We should look for the strongest such version and see if it is a continuity worth having. If there is no such notion of continuity worth having, then there is no sustainable version of realism. However, I hold that there is a continuity (admittedly of an approximate kind) at the structural level that is substantial enough to count and hence I hold that [structural scientific realism] is a sustainable version of scientific realism, and indeed . . . the only sustainable version. (2007, 144)

Poincaré enters the picture as being, in Worrall's view, the first figure to both present a version of the pessimistic metainduction and advocate a position similar to his own ESR. Worrall writes:

> There was continuity or accumulation in the shift [from Fresnel's theory of light to Maxwell's], but the continuity is one of *form* or *structure*, not of content. In fact this claim was already made and defended by Poincaré. And Poincaré used the example of the switch from Fresnel to Maxwell to argue for a general sort of *syntactic* or *structural realism*. . . . This largely forgotten thesis of Poincaré's seems to me to offer the only hopeful way of *both* underwriting the 'no miracles' argument *and* accepting an accurate account of the extent of theory change in science. (1989, 117, emphasis original)

This characterization of Poincaré as a historical precursor for contemporary ESR can be found elsewhere in the literature. For example, Zahar agrees with Worrall in characterizing Poincaré as an epistemic structural realist: "Poincaré's structural realism is in a sense a reversal of Quine's slogan: to be is to be quantified over (in some first-order theory); for according to Poincaré, only the universals, and more particularly the relations occurring in a unified and empirically successful theory, mirror the ontological order of things. As for the nature of the relata, it will forever remain hidden from us" (Zahar 2001, 37). Like Worrall, Gower (2000) designates Poincaré as one of the earliest adherents to structural realism, where Gower understands the term as follows: "In the case of 'structural' scientific realism, the central idea is that scientific theories do indeed provide information unavailable to us in observation and experimentation, but that information is about the form or structure, rather than the nature or content, of what is unobservable. Often, it is claimed, when one theory is replaced by another, it is information about the essential nature of what is unobservable that is replaced, rather than information about the structure of the unobservable" (73–74).

Gower goes on to state that "the idea of structural realism, broadly construed" (2000, 74) had been adopted by Poincaré, Duhem, Cassirer, Schlick, Carnap, and Russell. Gower proceeds to give an account of how several of these historical figures, among others, can be considered as latching onto particular tenets of structural realism. He begins the section on Poincaré by claiming, "The view we know as structural scientific realism was explicitly and clearly expressed by Poincaré" (80), a statement that is footnoted with references to the discussion of Poincaré's position in Worrall (1989, 1994), to Psillos (1995), and to Zahar (1996).

After a brief sketch of Poincaré's view (supplemented with the usual quotes from Poincaré's major works), Gower concedes that although from a modern perspective one might easily find something like the no-miracles argument and the pessimistic metainduction in Poincaré, one must ask whether this modern characterization misrepresents his position; Gower notes in particular the mind-dependent aspect of Poincaré's view we have described above (see Gower 2000, 101). In the end, though, Gower decides that the usual "rough" characterization of Poincaré is generally correct, writing: "For both Poincaré and Duhem, then, a defensible scientific realism must be structural in the sense that it attributes reality to the relational structure of a scientific theory" (86).

We think that there is widespread recognition that attributing ESR to Poincaré is a little rough and ready. For example, Domski (2000) explicitly argues that Poincaré's position should not be interpreted as straightforwardly realist.

We agree with her assessment and have argued that all three terms in the ESR classification of Poincaré's position (epistemic, structuralist, and realist) should be handled with care: each means something rather different for Poincaré than for Worrall (and for contemporary ESR in general).

The motivation for Poincaré's position also demands reexamination. As mentioned, Worrall (1989) uses the pessimistic metainduction to motivate his ESR: in order to avoid the antirealist thrust of the pessimistic metainduction, he urges a retreat from standard scientific realism to structural realism, wherein we commit ourselves to only the structural part of our theory and remain agnostic about the natures of the entities instantiating or undergirding those structures.

Worrall points to the preface and chapter 10 of *Science and Hypothesis* to argue that Poincaré both confronts the pessimistic metainduction and rejects it via his structuralism concerning scientific theories (Worrall 1989, 117–18). First, Worrall interprets the following passage from Poincaré as a version of the pessimistic metainduction: "The ephemeral nature of scientific theories takes by surprise the man of the world. Their brief period of prosperity ended, he sees them abandoned one after another; he sees ruins piled upon ruins; he predicts that the theories in fashion today will in a short time succumb in their turn, and he concludes that they are absolutely in vain. This is what he calls the *bankruptcy of science*" (Poincaré 1902/1952, 160; emphasis original). For the purposes of this discussion, we follow Worrall's interpretation of this passage, in which the bankruptcy of science is identified with the pessimistic metainduction. However, it should be noted that the phrase "bankruptcy of science" has a rich historical-contextual relevance, and Poincaré's use of it here is, consequently, laden with meaning that ought not be overlooked.[1]

Second, Worrall cites the following passage as providing the structural solution:

> The true relations between these real objects are the only reality we can attain, and the sole condition is that the same relations shall exist between these objects as between the images we are forced to put in their place. If the relations are known to us, what does it matter if we think it convenient to replace one image by another? In the case of contradiction [between two theories] one of them at least should be considered false. But this is no longer the case if we only seek in them what should be sought. It is quite possible that they both express true relations, and that

1. We will not explore this further here, but we point the reader to Paul (1968), esp. 301, 311, and 320. We thank a reviewer for alerting us to the special history of this phrase and for supplying relevant references.

> the contradictions only exist in the images we have formed to ourselves of reality. (Poincaré 1902/1952, 161, 163)

In other words, theories that contradict one another at the level of the images associated with them may be found to agree once we restrict our attention to the relations expressed by the theories. It is this observation (incorporated within Poincaré's epistemic relationism) that can be put to work in rejecting the bankruptcy of science. By focusing on the relations instead of troublesome entity talk, one can tell a continuous and progressive story about the history of scientific theories. Poincaré stresses that while the entities may change in the transition from one theory to the next, the form of the old theory is preserved: "Our equations become, it is true, more and more complicated . . . but nothing is changed in the relations which enable these equations to be derived from each other" (1902/1952, 181). A successful theory is not one that necessarily gets the entities right—indeed, recall that Poincaré is skeptical whether the truth of such claims can be evaluated at all—but instead, a successful theory is one that correctly describes observed relations and fails to affirm false ones. The very best theories are those throwing into relief the greatest number of known relations and thereby exhibiting "traces of definitive construction" (175). This reading of Poincaré constitutes a third argument for structuralism.

What is the relationship between the bankruptcy of science and Poincaré's structuralism? The standard interpretation, stemming from Worrall, is that the pessimistic metainduction is a motivation for Poincaré's structuralism. If this is correct, then Poincaré's position might similarly be understood as a retreat from scientific realism in the face of the pessimistic metainduction and might justly be thought of as a historical forerunner to Worrall's position.

It seems to us, however, that reading the inference as going from Poincaré's epistemic structuralism, independently grounded, to the rejection of the bankruptcy of science (rather than the other way around, as in Worrall's arguments) is a more plausible interpretation of Poincaré. This claim is supported by the structure of Poincaré's argument as set out in *Science and Hypothesis*. In this text, Poincaré is developing an epistemology of science that begins with arithmetic and geometry and goes on to explain the role of mathematical physics in the natural sciences. As we have discussed here, his central concerns are the status of arithmetic and geometry, and of objective knowledge, as those issues were understood at the turn of the century, and his solutions are rooted in his neo-Kantian epistemology. He is not primarily concerned with defending empirical science from antirealist arguments in the form of the pessimistic metainduction. In fact, it seems instead that after developing his position, Poincaré then considers the bankruptcy of science to be addressed by his very position in the manner of a corollary. Poincaré's discussion of the bankruptcy of science and its rejection by appeal to epistemic structuralism occurs in the tenth of thirteen chapters in *Science and Hypothesis*, only after he has already introduced, motivated, and elaborated his (multifaceted) structuralist position.

In short, we believe we have demonstrated that the pessimistic metainduction plays a much smaller role in Poincaré's overall considerations than is commonly believed and little if any in the arguments he makes for his position. This is not to say that one cannot use Poincaré's ideas to construct Worrall's argument for epistemic structuralism (and even ESR)—surely one can. The point is simply that this is not how Poincaré himself went about arguing for his position.

5. Conclusion

On Worrall's account, ESR is motivated by epistemic modesty, the grounds for which rest on a claim about history: as a matter of historical fact (so the claim goes), it has turned out that science has witnessed a series of ontological discontinuities concerning theoretical entities. There is nothing in Worrall's argument for ESR that warrants the claim that the development of science had to go this way or that it must continue to show such ontological discontinuities. ESR is thus consistent with a future in which the ontology of our best theories has been stable for such a long time that the pessimistic metainduction loses its force, and epistemic immodesty begins to regain its plausibility. In sum, the commitment to ESR is contingent on the history of science.

By contrast, neither the argument from generalization (Argument 1) nor the argument from objectivity (Argument 2) is historically contingent. The former argument rests on Poincaré's epistemology (specifically, his account of a priori intuition and its role in grounding our ability to generalize), while the latter rests on a specific claim about the nature of objective knowledge.

The argument from generalization is specific to scientific theories. The conclusion of the argument from generalization is that the generalizations constructed on the basis of the scientific facts (whatever the nature of these facts may be) must be structural. In considering this argument alone, one might think (contrary to Poincaré's overall position) that there could be nonstructural aspects to "the facts" (or at least to some of the facts). One might therefore also think that scientific theorizing could go astray if, when we generalize over the facts, we inadvertently "boost" nonstructural aspects associated with the facts up into the theories. According to the argument from generalization, such "boosting" of nonstructural aspects is illegitimate. Why? Because our ability to generalize is grounded in a priori intuition, and the generalizations that a priori intuition warrants are of a structural nature. The appearance in our generalizations of any nonstructural features of the fact must thereby be considered epistemically unwarranted. Thus, Poincaré's position is stronger than that endorsed by contemporary advocates of ESR because it follows from his account of how scientific knowledge is possible at all: rather than arising from a choice that we make about being epistemically modest in the face of history, it follows from what is epistemically warranted given our nature as knowers.

By contrast, the conclusion of the argument from objectivity (i.e., objective knowledge just is knowledge of relations) extends beyond scientific theories to objects of knowledge in general, including scientific facts. These too, according to Poincaré, are relational. The conclusion of this argument is therefore much stronger than the claim argued for by contemporary advocates of ESR.

Our primary goal in this article has been to clarify the ways in which Poincaré's views differ from current ESR. In so doing, we have taken into account the roles of his neo-Kantianism, his conventionalism, and his account of objectivity in informing his overall position. As we have shown, each of these requires that we interpret his position somewhat differently from contemporary ESR. Moreover, we have seen that Poincaré's position is motivated by two arguments not found in the current literature on ESR, as a result of which he can be understood as endorsing a stronger thesis than is associated with contemporary ESR. Current ESR is motivated primarily by the desire to overcome the pessimistic metainduction while doing justice to the no-miracles intuition. The two additional arguments for structuralism given here, and attributable to Poincaré, may perhaps offer alternative ways to think about structuralism within philosophy of science.

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