Poincaré's Aesthetics of Science

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Abstract

This paper offers a systematic analysis of Poincaré's understanding of beauty in science. In particular, the paper examines the epistemic significance Poincaré attributes to aesthetic judgement by reconstructing and analysing his arguments on simplicity and unity in science. I offer a consistent reconstruction of Poincaré's account and show that for Poincaré simplicity and unity are regulative principles, linked to the aim of science – that of achieving understanding of how phenomena relate. I show how Poincaré's account of beauty in science can be incorporated within his wider philosophy of science.

1. Introduction

This paper offers a comprehensive analysis of Poincaré's understanding of beauty in science and, in particular, his epistemic justification of simplicity and unity in science. I reconstruct Poincaré's account and show that for Poincaré simplicity and unity are regulative principles, linked to the aim of science - that of achieving understanding of how the phenomena relate. I investigate the epistemic significance Poincaré attributes to aesthetic considerations and argue that rather than linking beauty to truth, Poincaré links beauty to scientific understanding. In conclusion, I show how this account offers new insights into Poincaré's wider philosophy of science, particularly regarding the aim of science and scientific knowledge.

The structure of this paper is as follows. I start with a discussion of the beauty in science and offer an analysis of Poincaré's views on the role beauty plays in scientific practice. I argue that for Poincaré beauty reduces to simplicity and unity. In section three I investigate Poincaré's understanding of simplicity as an aesthetic property of theories. I argue that while simplicity plays a methodological role, Poincaré does not take simplicity to be linked to the truthlikeness of theories exemplifying it. Section four analyses the role of unity in science. I argue that Poincaré takes unity to be the ultimate goal of science which gives us understanding. In section five I explore how utility is linked to aesthetic judgement, Poincaré's account of creativity, and show the role of the aesthetic sensibility in selecting useful theories. I then explore the implications of this theory of aesthetics in science for Poincaré's overall philosophy of science and in particular his alleged realism about scientific theories. Section six is the conclusion.

2. Beauty in Science

Aesthetic judgements are an integral part of scientific practice. Scientists employ aesthetic judgements in the selection of phenomena to study, the construction of hypotheses, the evaluation of theories and in deciding their epistemic commitments towards a theory. Paul Dirac famously attributed to beauty a special epistemic role, claiming that "one has a great confidence in the theory arising from its great beauty, quite independent of its detailed successes" (Dirac 1980, 40). Dirac believes beauty is linked to truthlikeness and we can be confident in the truth of a beautiful theory independently of the data. Dirac claims that "[o]ne has an overpowering belief that [the theory's] foundations must be correct quite independent of its agreement with observation" (ibid.). Werner Heisenberg also claimed to believe in this intrinsic relationship between truth and beauty: "[i]f nature leads us to mathematical forms of great simplicity and beauty we cannot help thinking that they are "true", that they reveal a genuine feature of nature" (Heisenberg 1971, 68). James Watson claims that what convinced Rosalind Franklin, who had already considered the double

helix structure of DNA but believed some of the x-ray pictures she had produced gave evidence against it, was the fact that the double helix structure of DNA "was too pretty not to be true" (1968, 124).

Before we examine Poincaré's account of aesthetic considerations in science, it is worth starting with some central questions concerning the concept of beauty in particular. The first question, naturally, regards what beauty is: whether it is a reducible or irreducible property. Practising scientists often attribute properties of 'harmony', 'symmetry', 'simplicity' and 'unity' to theories they regard as beautiful, implying that beauty is reducible to a set of properties.[1] As I will show in this section, Poincaré offers such a reductivist account of beauty, taking beauty to reduce to simplicity and unity. This leads us to the second question that needs to be addressed: where do we find beauty? Beauty is attributed to a wide range of subjects: to phenomena, scientific theories, mathematical proofs, visual representations, scientific models, etc.. Poincaré himself attributed beauty to scientific hypotheses and theories as well as mathematical axioms and theories. The focus of this paper will be primarily on his arguments for the aesthetic value of scientific hypotheses and theories.

A third question that deserves attention is what function beauty plays in scientific practice. Here we can find several different stances – beauty can play a motivational role in scientific practise, it can be used as a heuristic guide or it can be regarded as a truth indicator. Poincaré himself believes that beauty gives us motivation to study nature (1908, 368). He also believes, like his contemporaries Pierre Duhem (1954) and Ernst Mach (1984), that aesthetic considerations can be heuristic guides in the resolution of theory choice. That is, if faced with two alternative theories that equally well fit the phenomena, one should choose the most aesthetically pleasing one. As we saw in the case of Dirac and Heisenberg, however, it is often believed that aesthetic considerations have a more fundamental, epistemic, role. According to this view, there is a special epistemic link between the aesthetic properties of a

[1] It is interesting to consider whether these particular properties are sought after in all scientific disciplines or whether they are particularly valued in physics and the mathematical sciences.

theory and its truth and we should believe in a theory's truthlikeness if the theory possesses aesthetic properties. I later illustrate that for Poincaré such a link cannot be justified.

A fourth important question concerns whether beauty is an objective property or is projected upon theories by us. Objectivist accounts take there to be an objective property we discover in the theories or the phenomena, while projectivist accounts claim that aesthetic judgements are simply subjective responses to certain properties of theories. In section 5 I argue that Poincaré takes an intermediate position.

The fifth and final question concerns the relationship between aesthetic value and empirical adequacy. According to James McAllister (1996), one can take aesthetic value to be independent from empirical adequacy or simply an aspect of it. According to the 'autonomist' view, empirical success and aesthetic value are independent of each other, allowing the latter to act as an indicator of the former. On the opposing account, there is nothing more to aesthetic appreciation of a theory than the appreciation that the theory is empirically successful.[2] As will become clear in the next sections, Poincaré aligns with the former thesis.

Before we can address these questions in further detail, we need to understand exactly in what context Poincaré employs the concept of beauty and whether beauty is analysed into other aesthetic properties. In the remainder of this section I focus on Poincaré's argument about the value of science and the motivational role of beauty and further show that for him beauty can be analysed into two properties we find in theories and the phenomena: simplicity and unity.

Poincaré develops an argument for the motivational role of beauty in science in the context of the value of science. The question whether science is valuable in itself or for its practical utility has long been at the forefront of political and social debate. The beginning of the 20th century is not an

[2] There is also a debate concerning whether aesthetic judgements are indeed aesthetic. Todd (2008) argues that aesthetic judgements are epistemic because they are associated with normative claims.

exception; the so called 'bankruptcy of science' fuelled enormous debates in France where scientists tried to defend the value of science despite its discontinuities and breaks from past advancements. Poincaré develops an argument in which he defends the continuity of science against the apparent 'revolutions' and discontinuities. It is during these debates that he tackles the question about the value of science.

Science can be valuable either in itself or for its products. Both in the *The Value of Science* and *Science and Method* Poincaré discusses Tolstoi's claim that 'science for its own sake' is an absurd idea: since time and resources are limited, we have to make choices with regard to which questions to explore; this choice is necessarily guided by utility. However, utility for Tolstoi is understood in terms of moral progress (Poincaré 1908, 363). Poincaré claims that while science cannot be done for its own sake due to practical constraints, science cannot be pursued for its products only, 'in view of an immediate application'. It is here that he brings the idea of aesthetic emotion: "[t]he scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is beautiful" (ibid., 368). Poincaré clarifies how he understands this concept of beauty:

> I am not speaking, of course, of the beauty which strikes the senses, of the beauty of qualities and appearances. I am far from despising this, but it has nothing to do with science. What I mean is that more intimate beauty which comes from the harmonious order of its parts, and which pure intelligence can grasp" (ibid.).

According to Poincaré the aim of science is to offer understanding of the underlying relations between phenomena. He argues that scientific theories offer "a classification, a manner of bringing together facts which appearances separate, though they were bound together by some natural and hidden kinship" (ibid., 347). It is in this underlying harmony or unity that our theories uncover that we find beauty.

Beauty, for Poincaré, is an aesthetic property that reduces to the simplicity and unity of our theories and we can have intellectual access to it: "every generalisation supposes in a certain measure a belief in the unity and simplicity of nature" (Poincaré 1902, 112). He furthermore states that: "[i]t is because simplicity and vastness are both beautiful that we seek by preference simple facts and vast facts" (ibid., 368). It is thus necessary for us to examine in further details his account of simplicity and unity.

This section started with five questions regarding the notion of beauty and how Poincaré develops this notion. We have seen that Poincaré develops a reductionist notion of beauty by analysing beauty as the unity and simplicity of scientific hypotheses and theories. Before analysing further the epistemic role for beauty, it is important to examine how Poincaré understands the notions of simplicity and unity. The next section presents Poincaré's arguments on the role of simplicity.

3. Simplicity

There are three issues regarding simplicity that I want to address in this section: (1) how simplicity is defined; (2) how it is used; and (3) how it is justified. The first issue is conceptual and concerns which understanding of simplicity Poincaré employs. Simplicity can be ontological (often referred to in the contemporary literature as *parsimony*), or syntactic (often referred to as *elegance*). Parsimony refers to the number and complexity of things a theory postulates. Parsimony, for example, was a driving consideration in the overthrowing of phlogiston theory, since the alternative theory developed by Lavoisier claimed equal explanatory power without adding an additional substance. Elegance, on the other hand, does not refer to the 'kinds' a theory postulates, but to the number of hypotheses and axioms of the theory. Syntactic elegance or simplicity can also be understood as the lack of complexity, ad hocness, or free parameters in a theory.

Poincaré uses simplicity mainly to denote syntactic elegance. However, he also stresses the importance of simplicity in the ontological sense. Despite

claiming that questions about ontology should be left to the metaphysicians, he allows one to postulate unobservable entities in one's theory if these offer useful fictional devices for prediction. When discussing the usefulness of the ether, he claims that:

> The object of mathematical theories is not to reveal to us the real nature of things; that would be an unreasonable claim. Their only object is to coordinate the physical laws with which physical experiment makes us acquainted. […] Whether the ether exists or not matters little—let us leave that to the metaphysicians; what is essential for us is, that everything happens as if it existed, and that this hypothesis is found to be suitable for the explanation of phenomena. […] [S]ome day, no doubt, the ether will be thrown aside as useless (Poincaré 1902, 156).

This quotation shows us that while Poincaré is not interested in addressing ontological questions, he allows the endorsement of an unobservable entity if it is useful for making predictions. Thus, the endorsement of an unobservable entity is only legitimate if it leads to an empirically successful theory that saves the phenomena.[3]

The second issue concerning simplicity is its role in scientific enquiry. We can understand simplicity as playing either an epistemic role or a purely heuristic role. One can take simplicity to be an indicator of truth and regard simpler theories to be closer to the truth than complex ones. Alternatively, one can take simplicity to play a merely heuristic role that allows one to rationally employ a simple theory for some end.

Poincaré argues for the instrumental role of simplicity. Simplicity is a guiding rule in a number of contexts, e.g. in the selection of facts when making generalisations and in evaluating and comparing competing hypotheses and theories. Aesthetic values guide our choice in the construction and selection of

[3] Poincaré's argument here is an instance of non-eliminative instrumentalism. Mach (1984), on the other hand, endorses an eliminative instrumentalism, arguing that "all metaphysical elements are to be eliminated as superfluous and as destructive of the economy of science" (Mach 1984 xxxviii).

hypotheses: “every proposition may be generalised in an infinite number of ways. Among all the possible generalisations we must choose, and we cannot but choose the simplest” (ibid., 99). When it comes to understanding whether simplicity is an objective property of facts, he answers in the negative. Simplicity is a guide to more useful theories:

> Are there such things as simple facts? And if there are, how are we to recognise them? Who can tell that what we believe to be simple does not conceal an alarming complexity? All we can say is that we must prefer facts which appear simple (1908, 365).

Whilst recognising the heuristic role of simplicity, Poincaré does not believe we can infer that simple laws reflect reality, that nature in itself is simple. Poincaré considers simplicity to be playing a very important regulative role in the advancement of science, but does not believe we should be drawing metaphysical conclusions from its role. This point is evident in his defence of Euclidean geometry. Poincaré famously discusses the empirical equivalence between a world with a Euclidean geometry and a world with a non-Euclidean geometry and compensatory distorting forces, and claims that our preference ought to be led by considerations of simplicity. He defends the use of Euclidean geometry as the simplest option because it is the most convenient (1902, 45). He explicitly takes this choice, led by simplicity, to be the most convenient and useful one but not to be the true one.

Poincaré argues that the history of science places doubt on the claim that nature itself is simple (ibid., 99-100). He argues that we cannot infer from the usefulness of simplicity that the world itself is simple. Simplicity should not be taken to be a guide to the true nature of reality. For Poincaré simplicity is a condition of our making: “We are therefore led to adopt the same course as if a simple law, other things being equal, is more probable than a complex law” (ibid., 100). Poincaré claims that while it could appear that simple laws govern reality, the history of science indicates that the phenomena are complex and

simplicity is sometimes only apparent. A closer exploration of the phenomena reveals deep complexity in nature:

> A century ago it was frankly confessed and proclaimed that nature loves simplicity; but nature has proved the contrary since then on more than one occasion. We no longer confess this tendency, and we only keep of it what is indispensable, so that science may not become impossible" (ibid., 100).

Poincaré famously uses the atomic theory to show that what was supposed to be a simple explanation of the phenomena turned into a complex one. He claims that while the atom was initially regarded as the fundamental building block of reality, it is full of complexity: "this atom is a world" (Poincaré 1913, 91).

Poincaré argues that even though we cannot know whether simplicity is a property of nature, it has to be a property of our theories and we should always try to generalise in the simplest possible way:

> [T]hose who do not believe that natural laws must be simple are still often obliged to act as if they did believe it. They cannot entirely dispense with the necessity without making all generalisations, and therefore all science, impossible. It is clear that every law can be generalised in a number of ways, and it is a question of choice. The choice can only be guided by considerations of simplicity [….] [E]very law is held to be simple until the contrary is proved (1902, 113).

Importantly, Poincaré argues that simplicity is a necessity of our making, a requirement from which we cannot free ourselves: "In formulating a general, simple, and formal law, based on a comparatively small number of not altogether consistent experiments, we have only obeyed a necessity from which the human mind cannot free itself" (ibid., 100).

This section started with three issues regarding Poincaré's understanding of simplicity: how simplicity is defined, used and justified. Regarding the first issue, we have established that Poincaré is mainly concerned with the mathematical elegance of scientific theories. It is the elegance of theories that is likely to strike the observer as beautiful. When it comes to the second issue – applicability of simplicity –, Poincaré takes simplicity to play a regulative role but is sceptical that we can make inferences about the world in itself. Simplicity does not lead us to true theories; rather, it aids the development of hypotheses, our choice of hypotheses, and ultimately guides our choice between theories that equally fit the data. The third issue concerns whether Poincaré offers any justification for simplicity. Poincaré takes simplicity to play a regulative role in that it promotes the development of useful theories that offer understanding of relations in the phenomena. While simplicity cannot be taken to be an indicator of a theory's truth, it plays an important epistemic role. In the next section I show that, for Poincaré, both simplicity and unity are regulative ideals linked to the aim of science.

4. Unity

So far I have argued that beauty for Poincaré is to be found in the simplicity and unity of scientific theories. We established that while simplicity plays a regulative role, it does not lead us to rationally believe in the ontology of a theory. Rather it justifies the use of a theory. Simplicity plays an instrumental role, but Poincaré is careful to note that he is not concerned with whether nature itself is simple or not. He notes that one might doubt the simplicity of nature by considering the history of science and the fate of past simple theories. However, the principle of simplicity and unity need to be followed as regulative ideals regardless of whether nature itself is simple or unified. The most intriguing part of Poincaré's argument concerns the relationship between simplicity and unity. In this section I show that unity is also taken to be a regulative ideal linked to the aim of science, that of understanding how the phenomena relate.

Unification is often appealed to by physicists when describing a theory as beautiful. Heisenberg, for example, claims that "[b]eauty is the proper conformity of the parts to one another and to the whole [….] The mathematical relation can therefore assemble two initially independent parts into a whole, and so produce beauty" (Heisenberg 1974, 174). He explains that theories like Newtonian mechanics greatly exemplify this – they are able to account for and connect a great variety of mechanical phenomena under a simple system of axioms. Richard Feynman claims that beauty stems from our understanding of how different elements fit into a greater whole. He argues that for a physicist beauty is felt when one can grasp the 'pattern' of nature; when one can appreciate how "two laws are connected so that reasoning alone will bring you from one to the other ... you will appreciate the beauty of the relationship of the statements" (Feynman, 1967, p. 41).

There are many cases in the history of science in which the unificatory power of a theory has been considered epistemically significant. Newton unified celestial and terrestrial phenomena under the theory of gravitation. Maxwell unified electric and magnetic phenomena with his theory of electromagnetism. Einstein's special and general theories of relativity achieved many levels of unification: unification of space and time into spacetime, the equivalence of mass and energy ($E=mc^2$), the equivalence of inertia and gravity, and finally, gravity is explained as a consequence of the variable curvature of spacetime. Unity is also often taken to be the ultimate goal of science with contemporary physics looking for a unification of all four fundamental forces (gravity, weak, strong, and electromagnetic) into a 'theory of everything'.

Like many contemporary scientists, Poincaré takes the aim of science to be the development of a unified theory that uncovers 'hidden relations' or 'hidden kinships' between the phenomena. For Poincaré it is through grasping the harmony between the phenomena that we achieve understanding of the nature of reality. He argues that it is not coincidental that we search for harmony in nature: "[w]e take elements which at the first glance are unconnected; these arrange themselves in an unexpected order, and form a

harmonious whole. We cannot believe that this unexpected harmony is a mere result of chance" (1902, 100).[4]

However, the unity of theories cannot be understood in either objectivist or projectivist terms. Unity is not an objective feature of the world outside our mental capacities; nor is it a subjective feature we project upon nature. Poincaré argues that unity is part and parcel of our intellectual capacities and an ideal we follow in our enquiries. Poincaré positions himself between an objectivist and subjectivist stance towards aesthetic judgement and takes aesthetic judgements to bear intersubjective validity. Aesthetic judgements are not simply emotional responses, differing between individuals with different tastes and preferences. Nor are they objective, since they do not refer to or reflect an objective property of a theory. It is reasonable to suppose that for Poincaré aesthetic judgements are objective in that there is intersubjective agreement between beings like us who share the same intellectual capacities.[5] Poincaré claims that "[t]his harmony is at once a satisfaction of our aesthetic requirements, and an assistance to the mind which it supports and guides" (1908, 396-397).[6]

When further assessing whether we can infer the simplicity and unity of nature from the usefulness of these two aesthetic properties, Poincaré argues:

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[4] Note here that Poincaré uses 'harmony' and 'unity' both as properties of theories and of the phenomena, and that he takes harmony to reduce to unity.

[5] While there is no explicit reference to Kant's aesthetic theory in Poincaré's writing, a middle position between objectivism and subjectivism would imply a Kantian influence here. According to Kant, aesthetic judgements depend on the subject's reflection on the object rather than in some property in the object itself. However, Kant claims that rather than being completely subjective emotional responses, aesthetic judgements demand the agreement of others and thus have intersubjective validity (Kant 2000).

[6] Note the parallels and differences here with Poincaré's contemporary Pierre Duhem. While Duhem argues that aesthetic values such as 'simplicity' and 'elegance' "are essentially subjective, contingent, and variable with time, with schools, and with persons" (Duhem 1954 , 288), there is still a need to explain how scientists come to an agreement about the aesthetic properties of theories. Just like David Hume, Duhem appeals to the concept of 'good sense', which an impartial scientist possesses. Duhem argues that scientists who have good sense can appreciate the aesthetic properties of theories because they are unbiased and objective. It is good sense that ensures that despite the subjective nature of aesthetic judgment, scientists with good sense can come to an objective agreement about the aesthetic properties of theories (see Stump (2007) and Ivanova (2010)).

> Every generalisation supposes in a certain measure a belief in the unity and simplicity of nature.[7] As far as unity is concerned, there can be no difficulty. If the different parts of the universe were not as the organs of the same body, they would not react the one upon the other; they would mutually ignore each other, and we in particular should only know one part. We need not, therefore, ask if nature is one, but how she is one. As for the second point, that is not so clear. It is not certain that nature is simple. (ibid., 112)

The following passages show that while acting as regulative ideals, Poincaré does not take simplicity and unity to be linked to truthlikeness. In *Science and Method* he claims that "we may dream of a harmonious world, but how far will it fall short of the real world?" (1908, 369). Similarly, simple theories often end up revealing deep complexities in the phenomena; he does not take it to be plausible to ask whether nature itself is simple and unified. We presuppose unity and simplicity as regulative ideals. Both simplicity and unity are linked to the goal of science; they are ideals to be followed in the search for the understanding of nature.

Unity is a guiding principle in the selection and evaluation of scientific hypotheses: "[i]t is, then, the search for this special beauty, the sense of the harmony of the world, that makes us select the facts best suited to contribute to this harmony; just as the artist selects those features of his sitter which complete the portrait and give it character and life" (368).[8] For Poincaré, beauty is to be found in the harmony our theories reveal. It is to be found in the hidden relations that our theories uncover and in their unification of apparently disconnected phenomena. It is this harmony that Poincaré takes to give us understanding.

With these elements of Poincaré's argument in place, we can finally address the question of justification posed in the previous section: how are

[7] 'Nature' is to be understood here as the objects of our experience.
[8] Morrison (2008) investigates the relationship between the unification project in contemporary physics and Kant's account of unification in the sciences.

simplicity and unity to be justified as aesthetic principles that guide scientific enquiry? I have argued that Poincaré justifies the use of simplicity and unity because they are linked to the goal of science – the acquisition of understanding. It is in revealing 'hidden kinships' and 'real relations' in the phenomena that Poincaré finds the aim of science accomplished and our understanding of nature fulfilled. As a consequence, Poincaré's account of aesthetic judgement in science is complex and sophisticated, offering new ways to think about aesthetics judgement in science. By reducing aesthetic judgements to judgements about the unity and simplicity of scientific theories, Poincaré offers an interesting reductivist account of aesthetic properties. In the next section I defend Poincaré's account by showing (a) the relationship between the aesthetic sensibility and utility, and (b) how these ideas fit his general philosophy of science.

5. Discussion

Having established a coherent reading of Poincaré's account of aesthetics of science, I want to further explore the implications of this account and its fit with Poincaré's overall philosophy of science. An interesting point worth addressing regards Poincaré's claims about aesthetic judgement and its link to utility. Poincaré explicitly highlights this link when stating that theories that can be regarded as an 'economy of thought' tend to be more useful:

> Thus we see that care for the beautiful leads us to the same selection as care for the useful. Similarly economy of thought, that economy of effort which, according to Mach, is the constant tendency of science, is a source of beauty as well as a practical advantage (Poincaré 1908, 369).

But how exactly does Poincaré articulate this link between utility and aesthetic judgement?

An interesting place to draw some insights and connections is Poincaré's discussion of beauty in mathematics and the role of the aesthetic sensibility in

selecting mathematical axioms and proofs. When discussing the case of creativity and mathematical discovery, Poincaré develops an account of creativity that gives central role to the aesthetic judgement of the mathematician which is explicitly linked to utility. According to his account, the creative process consists of four distinct but interconnected psychological phases: preparation; incubation; insight; and revision.[9] During the preparation process the thinker consciously studies the problem at hand and prepares for the incubation process. During the incubation process the mind is unconsciously working on the problem. It is during incubation that the mind has these 'sudden illuminations'. Incubation is necessarily preceded and followed by periods of conscious work, which ensures that the search for a solution is not too wide, open and unfruitful. Incubation, however, does not imply that the mind is not hard at work in trying to solve a problem; it only implies that this process is unconscious. During this period, Poincaré claims that the 'unconscious machine' is at work. Critical conscious reflection is vital in the period after the inspiration in order for the ideas to be evaluated and verified. As Livingston (2009) argues, Poincaré's account of creativity significantly differs from contemporary inspirationalist accounts of creativity, according to which the creative process is an unconscious activity of the mind. Poincaré's account offers a more complex understanding of creativity as a product of both conscious and unconscious processes.

An important aspect of Poincaré's account of creativity concerns how the mind becomes conscious of the creative ideas it has conceived during incubation. Poincaré argues that the useful mathematical ideas are the ones that trigger the mathematician's aesthetic sensibility. It is in this context that he appeals to mathematical elegance, simplicity and harmony that pure intelligence can grasp. Elegance and harmony give rise to an aesthetic emotion: "[t]his harmony is at once a satisfaction of our aesthetic requirements, and an assistance to the mind which it supports and guides" (1908, 396-397). The aesthetic sensibility "plays the part of the delicate sieve" which checks the result blindly generated by the mind and selects only the most elegant and beautiful

[9] For a detailed discussion of Poincaré's account of creativity, see Livingston (2009).

combinations produced (ibid., 397). We therefore see that for Poincaré the aesthetic sensibility can select the theories or proofs that best suit our aesthetic requirements. But he makes the further claim, that "[t]he useful combinations are precisely the most beautiful" (ibid.).

The link between practical utility and beauty raises the question whether the search for beauty is in any sense linked also to the acquisition of truth. As I noted in section 2, traditionally objectivist accounts claim that aesthetic judgements reflect objective properties of theories, and furthermore, that there is an epistemic link between a theory's aesthetic properties and its truthlikeness. Does Poincaré attribute to beauty such an epistemic link to truth? That is, does he regard the beauty of a theory as an indicator of its truth. At first sight it is difficult to attribute such a position to Poincaré. Traditionally he has been associated with a conventionalist or instrumentalist view of science, claiming that the aim of science is not truth but empirical adequacy. More recently, philosophers have claimed that his position is best understood as a form of selective realism, namely *structural* realism. John Worrall (1989), for example, claims that while Poincaré remains agnostic about unobservable entities, he is a realist about relations in the unobservable world discovered by our best scientific theories. Worrall argues that by giving up realism about unobservable entities such as atoms and electrons, Poincaré can account for the discontinuities in science by arguing that the revisions occurring in scientific revolutions concern ontological questions. [10] The relations between unobservables, however, remain unchanged. It is claims about 'structural' or 'relational' knowledge and clear opposition to ontological commitments that has convinced Worrall, Gower (2000) and Zahar (2001) that Poincaré's realism is structural.[11] These readings have explicitly noted that for Poincaré the aim of

[10] While opposing the atomic hypothesis for the majority of his life, Poincaré accepted the atom in 1912 claiming that there is sufficient experimental evidence for its existence. He draws (1913) an important distinction between the 'metaphysical' atom, which is supposed to be indivisible and unifying, and 'the atom of the chemist', for which there is sufficient evidence but which has proven to lead to more complexity. For more details on Poincaré's argument, see Stump (1989) and Ivanova (2013).

[11] According to structural realism, we can know the relations between unobservable entities, but not their properties (their nature). We can differentiate three mutually

science is not truth but empirically adequate theories that at the ideal end of science could offer knowledge of underlying relations.[12]

This reading sheds light on the idea that for Poincaré science cannot offer us the true underlying nature of reality and can at best give us relational knowledge – knowledge of how the phenomena are related. However, we can doubt even the idea that Poincaré is a structural realist. Poincaré claims on many occasions that we cannot reach the real nature of reality; that we only deal with appearances and our aim is to understand how the phenomena relate. His position has a neo-Kantian twist[13] that seems to challenge a structural realist reading of his position. He claims that we cannot discover a mind-independent reality, whether it is unobservable entities or unobservable relations, and that the phenomena we use for the construction of our theories are constructed by us.

> 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 it 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

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exclusive views regarding unobservable entities, which structural realists can endorse. A structural realist can be (1) agnostic as to whether there are unobservable entities. Or, (2) she can hold that there are unobservable entities, but our epistemic restriction does not allow us to know their 'nature' (that is, their first order properties). Or (3) a structural realist can employ the argument for coherence between epistemology and metaphysics and suggest that since all we can know is relations and not the entities themselves, then we should eliminate the unobservable entities from our ontology. This version is compatible with Ladyman's (1998) ontic structural realism.

[12] Ivanova (2015) has recently defined several different meanings of the term conventionalism associated with Poincaré's position and related it to his structuralism and neo-Kantianism.

[13] While Poincaré continued endorsing the synthetic *a priori*, he 'corrected' the Kantian framework in light of the existence of non-Euclidean geometries by claiming that they have *conventional* and not synthetic *a priori* status. Ben-Menahem (2006) gives a detailed account of Poincaré's conventionalism, while Friedman (1999) explains the neo-Kantian elements in Poincaré's epistemology. What concerns me here are the similarities between Poincaré's and Kant's theories of aesthetic judgement, that have not yet been noted in the literature.

> 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. (ibid.,14)

Scientific realists, including structural realists, are explicitly committed to the claim that our best scientific theories can discover a mind-independent structure of the world.[14] They are also often committed to the claim that super-empirical aesthetic criteria are guides to the truth. That is, it is often taken to be the case that beauty and truth stand in a special epistemic relationship. This relationship justifies our belief in the truth of a theory. In this section I have shown that Poincaré does not commit to either of these claims. He takes the aim of science to be not truth but understanding of how the phenomena relate. He takes our aesthetic judgements to be regulative ideals that we follow in our enquiries, and not principles that allow us to claim an aesthetically pleasing theory to be approximately true. The use of aesthetic considerations like simplicity and unity is justified because they are linked to the ultimate goal of science, to understand the relations among phenomena.

Contrary to the realist, Poincaré takes aesthetic properties of theories to be projected upon the theories by us. He nevertheless implies, in a very Kantian manner, that there is rationality in our aesthetic judgements due to there being intersubjective agreement. These Kantian elements of Poincaré's philosophy of science make his position even more intriguing than previously appreciated, making it difficult to situate him within the contemporary positions in the scientific realism debate. He departs significantly from the instrumentalist and realist views when it comes to the aim of science, and from the objectivist and projectivist views, when it comes to the nature of aesthetic judgement. These

[14] An exception is Massimi (2011) who develops an internalist neo-Kantian form of structural realism. Massimi claims that unobservable entities, and mathematical structures evolve together in relation to empirical evidence. Our best scientific theories do not represent a mind-independent reality (unobservable entities that exist independently of us). On the contrary, the unobservable entities, the mathematical structures evolve with the development of scientific knowledge. Massimi's position can be seen as a much more helpful way of thinking about Poincaré's own position in the scientific realism debate.

arguments open a new chapter for furthering our understanding of Poincaré's complex arguments.

6. Conclusions

In this paper I have offered a new exploration of Poincaré's aesthetics of science. I have argued that Poincaré takes aesthetic judgments to be central to scientific practice and our exploration of the world. I have investigated the relationship between simplicity and unity, which Poincaré considers as the ultimate aesthetic properties of theories. Poincaré takes simplicity and unity to be related to the ultimate aim of science: achieving understanding. He attributes to simplicity and unity a regulative role linked to the aim of science. For Poincaré beauty is indicative of understanding rather than truthlikeness. Moreover, Poincaré's account does not easily fall between the projectivist or objectivist views in aesthetics and also departs from a strictly realist position. These elements of Poincaré's theory of aesthetics open a new chapter into the study of Poincaré's complex views on the aim of science, aesthetic judgement and the role of the rational agent in it.

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