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the new axiomatix method: bachelard on the meaning and deformation of concepts

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INTRODUCTION

Interpreters of Bachelard have always been particularly engaged in demonstrating his actuality by insisting on those ideas that point towards a completely new approach and conception of science, and—more importantly—of philosophy and its relation to science. In doing so, they are wont to distinguish between those ideas that are novel and challenging, the marks of a flexible mind adjusting to new times, and those ideas that are atavistic remnants of the philosophical past, or of the present that Bachelard was just then revealing to have become outdated. In the analysis of Bachelard's reflections of science, the ideas that have been identified as the "actuality" of Bachelard are his conception of discontinuity between the scientific mind and common sense and the material dimension of his conception of science, as exemplified in his concept of phenomenotechnics and of the social nature of knowledge. But the champions of the revolutionary character of these ideas equally stress that Bachelard at times failed to maintain their revolutionary character, which led some to discern a truth behind Bachelard's philosophy, of which the latter is at times an unfaithful reflection. We see this, for instance, in how Latour and Woolgar or Lecourt respond to Bachelard's own elaborations of the social nature of science. Latour and Woolgar complain that Bachelard's "exclusive interest in 'la coupure épistémologique' prevented him from undertaking sociological investigations of science, even though many of his remarks about science make better sense when set within a sociological framework,"[1]. They suggest, in other words, that Bachelard failed to grasp the implications of the social nature of science. Lecourt, on the other hand, shows surprise at Bachelard's own theoretical elaboration on his conception of the social nature of science, namely as characterized mostly by a split within a single subject that introduces a normative element to his reasoning through internalized intersubjective control. For Lecourt, this seems to be a possible sign of "philosophical bad conscience."[2] These reactions are but some samples of complaints over the traditional tones to Bachelard's rationalism.

In this paper, I want to resist these attempts to "actualize" Bachelard, to distinguish between the forward-pointing and the retrograde elements of his thought. In my opinion, the actualization of Bachelard reduces his central ideas to vague inklings, to suggestive and imprecise phrasings of ideas with which later philosophers of science became infatuated. To do so, I will offer an interpretation of Bachelard's theory of concepts on which, contrary to what his constant insistence on discontinuity, his constant polemic against continuism would suggest,[3] Bachelard leaves much room for continuity in his image of science, and most remarkably, in his image of scientific concepts. More specifically, I will argue that, although Bachelard regards scientific concepts as amenable to historical change, he considers this as a change of the *same* concept. In order to substantiate this thesis, I will provide an account of Bachelard's conception of the meaning of a concept, and of what happens to this meaning as a concept changes. In offering such an account, I want to present the actuality of Bachelard, not as a precursor to discontinuist or social-constructivist approaches in the philosophy of science who failed to think through his own ideas, but as an inspiration to current attempts to bridge the gap between different approaches to philosophy of science.

The starting point of my interpretation is one of the traits Bachelard stably describes to the new scientific spirit in *The Formation of the Scientific Spirit*, *The New Scientific Spirit*, and *The Philosophy of No*, and that returns even more explicitly in *Applied Rationalism*. This repetition reveals that it is eminently important to him, even as he leaves his readers without any truly systematic treatment of it. I believe that a reconstruction of this recurrent idea can help us better understand Bachelard's theory of conceptualization, and its relation to his mathematicism and his dynamicism, by revealing how Bachelard meant to harmonize these two strands of his thought. He could, of course—or so I will argue—by recognizing that neither of these positions means quite what we expect them to mean.

The recurrent idea that I want to take as my point of departure is Bachelard's comments on the relation between comprehension, extension and application of concepts, for instance in a famous and suggestive passage from *The Formation of the Scientific Spirit*:

> In my opinion, the richness of a scientific concept can be measured through its capacity for deformation. This richness cannot be attached to an isolated phenomenon discovered to be richer and richer in characters, richer and richer in comprehension. Even less can this richness be attached to a collection that would gather round the most heteroclite phenomena, that would be extended, in a contingent manner, to new cases. The intermediary nuance would be realized if the enrichment in extension became necessary, as coordinated as the richness in comprehension.[4]

This passage, which continues with a discussion of the conditions of application of a concept and proceeds to introduce, all too summarily, the concept of a phenomenotechnique, is rich in concepts and notions, and difficult to penetrate. Part of my goal in this paper is to explain how Bachelard views the relation between extension and comprehension, both in the old and in the new scientific spirit. The key to understanding these and other similar passages is a brief and equally enigmatic statement from *Applied Rationalism*: "The extension and the comprehension, far from being inverse the one to the other, as is presented in the problem of classifications, would be, in some way, proportional."[5] Although this comment has not passed unnoticed in the literature, it has not received any systematic treatment either, perhaps because most readers share with Lecourt the idea that "[d]espite the terminology they borrow, these remarks are not the fruit of a study of Formal Logic; they derive from a direct reflection on the structure of scientific discourse"[6]. Although this judgment is not wholly erroneous, it does discourage serious attempts to understand what these remarks would mean "logically." I will argue in this paper that Bachelard's conception of the relation between the comprehension and the extension of a concept in the new scientific spirit is prompted by the role played by the axiomatic method in the science of his time, and that he is taking notice of important difference between the axiomatic method as it used to be conceived, and the axiomatic method as it is pursued in the new scientific era. In the first section, I will briefly introduce the old image of the axiomatic method, focusing mostly on those features that are at stake in Bachelard's discussion, namely the relation between generality and simplicity, and the role of general logical principles. In the second section, I will give a brief overview of the axiomatic method as envisioned through the Hilbert program, and forming the basis of both revolutions in mathematics and physics, most importantly the emergence of non-Euclidean geometry and non-newtonian mechanics, as well as the lessons Bachelard draws from it. In the third section, I will draw the implications of this picture of axiomatic thought for his view of the system of concepts and conceptualization. In the final section, I suggest a reading of Bachelard's theory of the meaning of concepts as one that allows them to persist through change and thereby harmonize his insistence on rationalism and progress with a historical and dynamical picture of science many take to imply radical discontinuity.

THE AXIOMATIC METHOD IN EARLY MODERNITY

In this first section, I will briefly sketch the main interesting features of the mathematical method in philosophy, and its implication for the conception of a concept, in the Early Modern period, and especially the 18th century. This restriction to the 18th century is not gratuitous: it is inspired by Bachelard's own interest, in the *Formation of the Scientific Spirit*, in the nature of this spirit in the 18th century. Although the mathematical method was a major source of inspiration for early modern philosophy, there were also major disagreements on its nature, its scope, and its utility. Bachelard's own position towards mathematics seems to resonate with that of the early modern period. Specifically, Bachelard seems sensitive to the connection between the major epistemological obstacles faced by the eighteenth century, pre-scientific spirit and the "esprit géométrique" of this period.

That respect for mathematics, and in particular for the accomplishment that is Euclid's *Elements*, was great in both antiquity and modernity, hardly needs reminder. What is important, however, is that the philosophical interpretation of the virtue of mathematics changed substantially. Agreement on the idea that mathematics is the paradigm of real knowledge can obscure intense disagreement on what this means for epistemology. Many Early Modern authors saw themselves as struggling to shake off the yoke of the Aristotelian interpretation of the axiomatic method. For the Aristotelians, at least as read by their early modern critics, the axiomatic method consists of deriving from high-level, highly general principles, principles that either form the basis of the specific science at issue, or are so general that they transcend the boundaries of different sciences, more specific consequences.[7] The great logical tool for connecting the various levels of this hierarchical system of principles and concepts is deduction, more specifically the syllogism.

In the early modern period, this picture of the scientific method is attacked from various angles.[8] Most famous and influential are the attacks mounted by Bacon and Descartes. In the Novum Organum, Bacon attacks the deductive, syllogistic method of the Aristotelians, and seeks out a variety of sources of bias that stand in the way of the proper scientific method. A central complaint of Bacon against the Aristotelian method is that the latter jumps all too precipitately to the most general concepts, where these should be formed through extensive empirical inquiry into all the various phenomena that could be relevant to that concept.[9] Bachelard discusses the Baconian method of inquiry in the *Formation of the Scientific Spirit*, for instance in commenting on the example of a call for research on the nature of coagulation by the Académie des Sciences in 1669, commenting that we see there "phenomena of a most diverse, most heteroclite nature, incorporated under the heading: 'coagulation'."[10] Bachelard regards this as a clear instance of the Baconian spirit, which he seems to chastise as insufficiently appreciative of the scientific need for theoretical and conceptual guidance.[11]

But Bachelard is not just critical towards the fumbling empiricism he finds in the Baconian tradition. He also attacks the Cartesian doctrine that became the core of what the Early Moderns called the geometric Spirit. The Cartesians agreed with Bacon's criticism of the Aristotelian idea that high-level generalities are the key to science. They correspondingly criticized the Aristotelian interpretation of the role of the axioms in the geometric method, according to which the solidity of the geometric method stemmed from two sources: the evident nature of the first principles, and the validity of the deductive methods which transferred evidence or certainty from the axioms to the theorems. For Cartesians, the certainty of mathematics was not due to either of these elements: Aristotelians overestimated both the role of first principles and of deductive procedures in the scientific process. According to them, the excellence of mathematics derived largely from the clarity of its concepts. Mathematicians, so Cartesians like Arnauld[12], Pascal[13] and even Locke[14] argued, were capable of certain knowledge because they made sure that their ideas were sufficiently simple and clear, and that they reasoned only on what they immediately recognized to be evidently true of these ideas and their mutual relations. Far more important than the tissue of principles and deductions is the transparent content of each individual concept. In this way, in early modernity, the superiority of the mathematical method, exemplified in Euclid's geometry, came to be regarded as due to the simplicity and clarity of the concepts used in it, more than due to the logical connections between its axioms, postulates and theorems.

The concepts central to Early Modern science were thought to relate to each other according to a law, namely the law that states that more general concepts are poorer in content, and involve less concepts. Kant formulated the law as follows: "[t]he content and extension of a concept stand in inverse relation to one another. The more a concept contains *under* itself, namely, the less it contains *in* itself, and conversely."[15] This means that a concept's extension is inversely related to its intension, i.e. the more particulars fall under it, the less concepts are contained in it, and vice versa, which implies that the most general concepts are the most fundamental concepts, and they themselves involve the least concepts.

To illustrate this with a well-known Aristotelian example, namely the relation between the concepts of animal and of human. The intension of such a concept could be interpreted as the list of criteria which an object must satisfy to fall under this concept. Such criteria are themselves the concepts under which an object must jointly fall in order to fall under the concept specified through it. In our Aristotelian example, the intension of the concept of animal would be "sensing living natural being." This concept has a greater intension than, for instance, that of living being, because the latter contains all the same criteria, but lacks the criterion of sensation. On the other hand, the concept of "human" would have a greater intension, because it contains all the criteria for being an animal, but adds a further criterion, i.e. reason. The more specific a concept, then, the greater its intension. But the same example shows how the extension decreases as the concept becomes more specific, as all humans are animals, but not all animals are humans, i.e. there are more things that are animals than there are things that are humans.[16]

Ideally, the fundamental concepts of scientific thought should have no content except for themselves, should be simple and immediately clear. For Bachelard, who frequently refers to the "esprit géométrique," the formulation of this idea by Pascal is perhaps most significant. According to Bachelard, the latter spirit consists in defining only that which needs definition, and to seek no definition of words that are perfectly simple and perfectly general:

> [Geometry] doesn't define any of the things like space, time, movement, number, equality, nor those many like them, because these terms naturally

denote the things they signify, to those who understand the language, such that the clarification one would make would bring about more confusion than instruction. For nothing is weaker than the discourse of those who wish to define primitive words.[17]

Pascal himself notes the irony that geometry doesn't define any of the terms that denote its own principal objects, but regards the perfectly simplicity and transparency of these objects to be the great virtue of this science. The axiomatic method, to early moderns like him, did not mean the deductive science inferring from general principles the content of a science, but was rather characterized by the following main features:

1. The more general and basic a concept, the simpler it is.
2. In science, we should strive to reason on the basis of simple ideas, and hence should seek to reduce complexity to simplicity, in order to ensure precision.
3. In the case of more general concepts of which we do not yet have the content, we should abstain from postulating one, and merely study the broadest possible extension of the concept.

Throughout his works on the New Scientific Spirit, Bachelard seeks to show how more recent developments in the sciences have decisively rejected this procedure in science. In what follows, I will argue that he agrees with the early modern insistence on the implications of the geometric method for the nature of scientific concepts rather than on its deductive method, and that he believes recent evolutions in the axiomatic method also call for changes in our conception of scientific concepts.

THE NEW GEOMETRICAL SPIRIT

The new geometrical Spirit, the new axiomatic method that emerged in the 19th century and became dominant in the early 20th was based partly on a development in geometry, namely the investigations on the parallel postulate. Whereas the old axiomatic method was based on the exemplary role of Euclidean geometry, the new axiomatic method was based on that of non-Euclidean geometry. In this section, I want to argue that Bachelard's insistence on non-Euclidean geometry in the *New Scientific Spirit* is due to his appreciation of the new axiomatic method, and that, to him, the new axiomatic method is philosophically relevant because of what it teaches us about concepts, concept formation and concept application. I will first describe the new axiomatic method, insisting on features that are relevant to my discussion of Bachelard's theory of concepts and conceptualization.

A seminal starting point for the description of the axiomatic method is a lecture by David Hilbert from 1918, titled "Axiomatic Thought"[18]. In this lecture, Hilbert set out to explain the new agenda for science set by the new Axiomatic method. According to Hilbert, any sufficiently advanced field can be axiomatized in the following way:

> When we assemble the facts of a definite, more-or-less comprehensive field of knowledge, we soon notice that these facts are capable of being ordered. This ordering always comes about with the help of a certain framework of concepts [*Fachwerk von Begriffen*] in the following way: a concept of this framework corresponds to each individual object of the field of knowledge, and a logical relation between concepts corresponds to every fact within the field of knowledge. The framework of concepts is nothing other than the theory of the field of knowledge.[19]

He continues to note that this ordering allows us to recognize certain basic principles underlying the field:

> If we consider a particular theory more closely, we always see that a few distinguished propositions of the field of knowledge underlie the construction of the framework of concepts, and these propositions then suffice by themselves for the construction, in accordance with logical principles, of the entire framework.[20]

This results in what is likely to be the traditional image of the axiomatic method, namely as method that determines the first principles of a theory or domain and then derives conclusions through mere deduction:

> These fundamental propositions can be regarded from an initial standpoint as the *axioms of the individual fields of knowledge:* the progressive development of the individual field of knowledge then lies solely in the further logical construction of the already mentioned framework of concepts.[21]

This seems to suggest that Hilbert regards a science as virtually complete once its foundations have been laid, and the development of that field to be an issue of logical deduction. But this misses an important second aspect of the axiomatic method, which results from the idea that the basis can itself be questioned:

> in the cases mentioned above the problem of grounding the individual field of knowledge had found a solution; but this solution was only temporary. In fact, in the individual fields of knowledge the need arose to ground the fundamental axiomatic propositions themselves. So one acquired 'proofs' of the linearity of the equation of the plane and the orthogonality of the transformation expressing a movement, of the laws of arithmetical calculation, of the parallelogram of forces, of the Lagrangian equations of motion, of Kirchhoff's law regarding emission and absorption, of the law of entropy, and of the proposition concerning the existence of roots of an equation.
>
> But critical examination of these 'proofs' shows that they are not in themselves proofs, but basically only make it possible to trace things back to certain deeper propositions, which in turn are now to be regarded as new axioms instead of the propositions to be proved. The actual so-called *axioms* of geometry, arithmetic, statics, mechanics, radiation theory, or thermodynamics arose in this way. These axioms form a layer of axioms which lies deeper than the axiom-layer given by the recently-mentioned fundamental theorems of the individual field of knowledge. The procedure of the axiomatic method, as it is expressed here, amounts to a *deepening of the foundations* of the individual domains of knowledge—a deepening that is necessary for every edifice that one wishes to expand and to build higher while preserving its stability.[22]

The progress of the axiomatic method is thus a movement in two directions: one towards the consequences of the axioms, and one towards the foundations of the axioms. Hilbert himself regards the second movement as required for the former. Moreover, his main concern seems to be that of the unity of science, and he regards the deepening as a move towards unification. I suspect he believes that, without ensuring the consistency of two fields by grounding their axioms in a deeper field, the results of the different fields might give rise to contradictions. Hilbert concludes by stating that it is through the axiomatic method that mathematics acquires a leading role in science:

> anything at all that can be the object of scientific thought becomes dependent on the axiomatic method, and thereby indirectly on mathematics, as soon as it is ripe for the formation of a theory. By pushing ahead to ever deeper layers of axioms in the sense explained above we also win ever-deeper insights into the essence of scientific thought itself, and we become ever more conscious of the unity of our knowledge. In the sign of the axiomatic method, mathematics is summoned to a leading role in science.[23]

It would be an error, however, to regard the role of the axiomatic method as solely one of either providing an a priori source of scientific theorems, or a source of unification. Much more important for Hilbert is the two tasks it sets on assessing a system of axioms:

> If the theory of a field of knowledge—that is, the framework of concepts that represents it—is to serve its purpose of orienting and ordering, then it must satisfy two requirements above all: *first* it should give us an overview of the *independence* and *dependence* of the propositions of the theory; *second,* it should give us a guarantee of the *consistency* of all the propositions of the theory. In particular, the axioms of each theory are to be examined from these two points of view.[24]

Together, these two tasks can serve the purpose of clarifying the concepts of this theory by showing how and whether different propositions following from the system are dependent upon each other, and how and whether they are consistent with each other. An important comment Hilbert makes in this context is that "*electrodynamic inertia* and *Einsteinian gravitation* are compatible with the corresponding concepts of the classical theories, since the classical concepts can be conceived as limiting cases of the more general concepts in the new theories"[25].

This gives us a more central role of the axiomatic method: the ability to test anew the concepts of a theory by showing how they relate, and whether they in fact contradict certain other concepts, in case we are otherwise badly placed to assess these. These properties are, I believe, central to understanding Bachelard's own interest in the axiomatic method. Hilbert does not figure centrally in Bachelard's work, but when he does figure in it, it is as a reminder of the axiomatic method. In the context of a discussion of Gustave Juvet's work on the relation between the axiomatic method and the recent developments of physics, Bachelard quotes the famous opening lines of Hilbert's *Foundations of Geometry*:

> Let us consider three distinct systems of things. The things composing the first system, we will call points and designate them by the letters A, B, C, ...; those of the second, we will call straight lines and designate them by the letters a, b, c, ...; and those of the third system, we will call planes and designate them by the Greek letters α, β, γ, ... The points are called the elements of linear geometry; the points and straight lines, the elements of plane geometry; and the points, lines, and planes, the elements of the geometry of space or the elements of space.[26]

What is remarkable about this opening is that it does not start from the notions of points, lines and planes. Rather, it introduces these notions as names of three distinct systems of things. The work than proceeds to characterize these systems through axioms. This is regarded as an effort of abstraction and formalization: an effort is made to think, under these concepts, no more than what is explicitly attributed to them through the axioms, and these axioms are, correspondently, regarded as offering an implicit definition of these concepts. Bachelard comments on the passage as follows:

> All precautions have been taken, then, to ensure that the comprehension of objects is, so to say, a comprehension from above and not from below, as the comprehension of substantial origin was. Stated yet otherwise, these are uniquely relation, and in way substantial qualities.[27]

This passage indicates that, for Bachelard, a central feature of the axiomatic method is that it characterizes concepts and objects through their mutual relations, rather than internally. Important for my present purposes is that he describes this as a shift in the notion of comprehension or intension. For the previous conception of a concept, the thing was thought through its comprehension "from below," for the new axiomatic method, it is thought through its comprehension "from above." This comprehension from above, the context reveals, is the comprehension as implicit definition through axioms and other such relations.

It is this distinction between two conceptions of comprehension which allows us to understand Bachelard's otherwise rather enigmatic, and seemingly illogical statement, that in the new scientific spirit, a concept is generalized by adding to its comprehension. I will here briefly present an analysis of the *New Scientific*

Spirit according to which this "intensional enrichment" comprises two component movements.

Bachelard means to show this through various examples, but I will focus here on his discussion of non-Euclidean geometry and non-Newtonian mechanics. Of non-Euclidean geometry, Bachelard writes the following:

> One could say, in a paradoxical manner, that the starting point of non-euclideanism consists in the purification of a pure notion, in the simplification of a simple notion. In fact, [...] one ends up wondering whether the straight line with the parallel doesn't correspond to a special straight line, to a notion that is too rich, in short, to a notion that is already composite.[28]

Bachelard is commenting here on the movement through which one realizes that the line as we consider it in Euclidean geometry is not a simple notion, but rather a composite one, and that it is therefore only a special case of the line. If we were to eliminate the special restrictions, we would arrive at a simpler, more general notion, and thereby extend the notion of line to new geometries. This sounds natural enough as a reading, but it also seems to say the exact opposite of what Bachelard seems to hold about the relation between extension and intension in the new scientific spirit, namely that it generalizes through enrichment in comprehension. Here, Bachelard seems to say that in non-Euclidean geometry, we realize that a concept we thought was perfectly general and perfectly simple is, in fact, complex and therefore restricted. Sure enough, the comprehension is enriched in this case, but no extension seems to be won. And the concept of a line is extended beyond the case of Euclidean geometry, but only, it seems, through further simplification. The old law linking intension and extension as inversely related is upheld perfectly.

This initial puzzle, I want to suggest, rests on a confusion, and more precisely a confusion about the shifting meaning of comprehension in the two statements. The above story describes the process of generalization of the concept of a line from the perspective of its comprehension "from below," namely the internal meaning. In this respect, it is perfectly true that the notion of a line in Euclidean geometry is revealed to contain hidden specifications, and that the removal of these specifications yields a more general concept. But Bachelard also wants us to consider the idea from the perspective of the comprehension "from above": "the pangeometry eliminates arbitrary presuppositions, or rather she neutralizes them by the sole fact that she *seeks to offer a complete picture of all presuppositions*."[29] I propose that we read this passage in the following manner: the process of generalization through which the axiomatic method arrived at a more general concept of line, not restricted to the Euclidean case, is indeed one whereby the concept is purified. But this was possible only by increasing the amount of relations to be specified between concepts, and the internal criteria of application for the concept. Only by effacing the need to specify a variety of possible variations along several dimensions could the concept of a line in euclidean geometry be regarded as simple, and it is this simplicity that prohibited its generalization. Ironically then, the higher generality of the concept of a line in geometry is gained through the multiplication of relations between concepts and of parameters to be specified. Bachelard makes a similar point with respect to the concept of mass in non-Newtonian mechanics:

> Naturally, [...] it would be all too easy to find the classical mass as a particular case of relativist masses. For this, it would suffice to efface the internal mathematics, to suppress all the theoretical finesse that would yield a complex rationalism. We would find back the simplified reality and the simplified rationalism. Hence, we would deduce, by effacement, Newtonian mechanics from Einsteinian mechanics, without ever being able to make the inverse deduction, in detail or in the whole.[30]

The process of specification to the restricted case is regarded here as a process of effacement of precisely the complexity of theory and of the internal mathematics of a notion. The restricted case is not a product of specification, of complication, but of simplification. This is essential to Bachelard's philosophy, and reveals that, by comprehension he means the rich structure of the theory as that which delivers meaning, rather than the content of an individual concept. Concepts can be generalized once their solipsism is opened up, i.e. once they are revealed to have a rich content, consisting of all the choices and suppositions made, and all the parameters the values of which were held fixed rather than variable. Here, we find the conceptual holism which other commentators[31] have found in Bachelard. The meaning of a concept reflects the theory in which it is embedded, and grows as its relations within this theory become more elaborate and precise.[32]

INTENSIONAL ENRICHMENT AND PHENOMENOTECHNIQUE

From the cases described just now, Bachelard draws a further lesson:

> When one makes the balance of knowledge in the system of the 19th century and in that of the 20th, with respect to particular concepts, one must conclude that these concepts have enlarged by becoming more precise and that they can no longer be taken to be *simple*, except to the extent that one remains content with *simplifications*. Before, it was imagined that it was through application that concepts became complicated—it was believed that concepts were always applied well or poorly; considered in themselves, they were believed to be simple and pure. In the new thought, the effort of precision is no longer made at the moment of application: it is made at the origin, at the level of principles and concepts.[33]

Bachelard's picture of past thought is that there, concepts were thought to be perfectly simple and general in themselves, and that the problem of precision were an issue of application: a concept is immutable and perfectly general. The problem of application is the problem of our relating the concept to reality, of relating its comprehension to its extension. Here, we might be in error, due to the complexity of nature and the finite nature of our capacities. For Bachelard, however, the problem of complexity and precision is proper to concepts themselves. The process through which a concept becomes applicable is that through which it also loses its vagueness, through which it is opened up to reveal the parameters, the compatibilities and incompatibilities, that it hid from sight in its simple or simplified form. This rejoins the crucial passage from the *Formation of the Scientific Spirit*, which I will repeat and complete:

> In my opinion, the richness of a scientific concept can be measured through its capacity for deformation. This richness cannot be attached to an isolated phenomenon discovered to be richer and richer in characters, richer and richer in comprehension. Even less can this richness be attached to a collection that would gather round the most heteroclite phenomena, that would be extended, in a contingent manner, to new cases. The intermediary nuance would be realized if the enrichment in extension became necessary, as coordinated as the richness in comprehension. In order to incorporate new experimental proofs, one ought to deform primitive concepts and study the conditions of application of a concept in the meaning of the

> concept itself and should especially incorporate the conditions of application of concept in the meaning of a concept itself.[34]

We are now in a better position to assess the relation between conditions of application and comprehension. The analyses of the previous sections revealed that, for Bachelard, a concept becomes more general as it is more exactly characterized by explicating the suppositions, the parameters, the conditions laying behind it. Only when subsumed under a rich system of concepts, only when the relations between these concepts become fully specified, can the full extension of the concept be properly assessed. But in this case, it also becomes clear how it is applicable to the situation. The various parameters to be considered in applying the concept are not extraneous to it, are no external complications, but are part of its meaning, in the sense of its comprehension from above.

But the explicitation of meaning in this way has a further important benefit. It reveals possibilities that were unfathomed before. For the Cartesian image of a concept, the modalities regarding this concept were considered to be seen, immediately and clearly, in the concept itself. The possibility of its generalization to another case, the restriction to a specific case, or the applicability to an unconsidered case, were all seen directly as part of the concept. By opening up the concept, but understanding its meaning through its complex relations and the axiomatic system in which it figures, new possibilities are recognized. Two parameters which were previously seen as organically related can now be regarded as independent. More important, assumptions that were previously considered ludicrous now become a possibility. In the case of geometry, this became the suspicion that non-Euclidean geometries might be consistent, and that the concepts of points and lines did not automatically preclude a geometry where the parallel postulate does not hold. But it also suggests important things for physics. In the *Philosophy of No*, Bachelard describes the case of Dirac's concept of a negative mass:

> For the scientist of the 19th century, the concept of a negative mass would have been a monstrous concept. It would have been a fundamental sign of an error in the theory that would have produced it. [...]
>
> It is in this way that the dialectical philosophy of "why not?," which is characteristic of the new scientific spirit, enters the scene. Why can't mass be negative? Which essential theoretical modification could legitimate a negative mass? From which experimental perspective would we

> be able to discover a negative mass? [...] In short, the theory holds strong, she doesn't hesitate, at the expense of some modifications at the base, to search for realizations of an entirely new concept, without roots in common reality.[35]

This passage again contrasts the older conception of a concept, which has a clear inner comprehension, excluding and including certain possibilities necessarily, with the new conception as concerned primarily with a concept's impossibility from the perspective of the total system of concepts. Here, we see again the axiomatic method, which explicitly asks the question of independence and consistency, and tries to envisage a system in which the assumption of negative mass would turn out coherent. By mathematically elaborating the concept of mass, Dirac uncovered new possibilities, possibilities previously considered ludicrous a priori. One of the core virtues of the new axiomatic method is to create these new possibilities through mathematical analysis.

But this does not just happen through mathematical analysis. Bachelard reveals that the concept of negative mass as a possibility prompts at least two questions, namely:

> 1. How must our theory be altered such that this concept can be coherent and consistent with the rest of the theory?
> 2. What would it mean to discover, by means of an experiment, such a negative mass?

The second question, Bachelard immediately proceeds to clarify, is the issue of realization. The new conceptual possibility generates a new concept, and the new scientific spirit is thereby prompted to realize this concept, which is, Bachelard notes "without roots in common reality."

This is how the axiomatic method also steers research: we are not just dealing with a theoretical exercise, but we are already thinking about a possible experience that would instantiate that theoretical insight. This realization, this possible experience, we all know, must be constructed, by the mediation of theoretically informed instruments, in what he calls phenomenotechnique. What these realize are new possibilities, new concepts, and, since these concepts are thought through their relations, new relations between concepts. In experiments, concepts are pitted against each other, their boundaries and relations are put to the test, put under stress, and this, of course, can happen only if their relations are precise, are explicit. If the concepts remain too vague, if the relations between them remain imprecise, no experiment, no observation can be instructive on them.

This is part of Bachelard's anti-Baconianism. It is not that we must not strive to take into account the whole extension of a concept, nor that our concepts cannot be informed by our experience. It is rather that it is a precise concept, formulated in advance, which must be put to the test in its extension. And here, the instances are less informative than the constructed case where the boundaries of this concept, its ability to be precisified in these different contexts, and its precise relations and differences with other conferences, become realized.

But Bachelard warns us that it is a mistake to think of the phase of theoretical reflection and that of theory testing as two-distinct phases. If one does so, one is considering theoretical reflection in science as abstract reasoning in which one (largely qualitatively) appreciates the implications of one's theory, and only later devises a method to test the truth of a hypothesis. In such an attempt, the precisification and the conditions of application of a concept are relevant only when one proceeds to the testing phase. For Bachelard, such a view misunderstands both the fruitful role of experimentation in concept-formation, and the productive role of mathematics in theorizing. In his view, new theoretical vistas can be reached only through mathematical precision, and the latter is always partly motivated by questions concerning experimental set-up and measurement.

This reveals that, for all his talk of instruments, technology and practice, Bachelard's philosophy remains a philosophy of concepts, or more precisely of concepts and their relations. Concepts, however, cease to be pre-given, individual entities, but become rather nodes in a structural network of relations, determining possibilities, and conditions of application. Shifts in these relations, unsuspected possibilities, prompt further experimentation, which is the attempt to instantiate a possibility, to put to the test, not a theory, but a relation between concepts, and perhaps most importantly, to test the capacity for *deformation* of concepts.

CONCEPT FORMATION AND CONCEPT DEFORMATION

In the passage of the *Formation of the Scientific Spirit* on which this paper is ultimately a long commentary, Bachelard uses the notion of deformation twice to characterize what happens to scientific concepts. I want to finish with a suggestion on how to read this idea, and what it serves to reveal. The puzzle offered by Bachelard's philosophy, and by similar philosophies insisting on both the structural, holistic nature of systems of concepts and historical change, is that they incur challenges in explaining the continuity of concepts. In itself, this might be thought unimportant for those interested in the historical discontinuities characterizing science. Read from this perspective, Bachelard does not have a problem: he can simply insist that, underlying the stability of the term, the concept, e.g. of "mass" or of "line" has changed irrevocably, such that it is no longer the same concept. The stability of the term perhaps fools some philosophers, who fail to pay close attention to the development of the sciences, that the same concept is at stake, whereas in fact we are now in an incommensurable system of concepts, where the original term takes on a completely new meaning.

But this does not seem to be what Bachelard imagines as the progress of science. Sure, the scientific spirit itself is marked by discontinuities, and methods can be valid in one historical phase and invalid in the next. But this does not mean that the system of concepts succeed one another discontinuously. This is already suggested by Bachelard's own statements on how earlier sciences relate to later, how Euclidean geometry relates to the pangeometry of the new era, how Newtonian mechanics relate to Einsteinian mechanics:

> The generalization by the no ought to include what it denies. In fact, the whole spring of scientific thought for the past century stems from such dialectical generalizations with the envelopment of what they deny. In this way, non-Euclidean geometry envelops Euclidean geometry, non-Newtonian mechanics envelops Newtonian mechanics: wave mechanics envelops relativist mechanics.[36]

For Bachelard to be able to say this, some relation between two historical phases of the same concepts must be maintained, such that we can reasonably say that it is still the same concept. This should not be a surprising result, since Bachelard insists time and time again on the historicity of concepts, and a concept could not have a history if it can only be replaced. We should take the language of generalization more at face value: for a concept to become generalized, it is necessary that *it* be opened, that *it* become more complex, that *it* reveal its relations to other concepts, its precise conditions of applications. It is not the case that one concept is replaced by another, that a concept changes if its comprehension, i.e. its meaning changes. Again, in the crucial pages of the *Formation of the Scientific*

Spirit, we read:

> Scientific conceptualization requires a series of concepts on its way to be perfected in order to receive the dynamism that I'm aiming for, in order to form an axis of inventive thoughts.
>
> This conceptualization totalizes and actualizes the history of a concept. Beyond history, pushed by history, it solicits experiments in order to deform a historical stage of the concept. In experiment, it seeks occasions to *complicate* the concept, to *apply* it in spite of the resistance of this concept, in order to realize the conditions of application that reality never brings together.[37]

This famously historicist and developmental picture of science is a picture of conceptualization. Conceptualization is continuous process whereby the different historical stages of a concept are deformed, or rather, are prompted to be deformed by complication *cum* application, and the concept at any historical stage is marked by the history of these deformations. A concept is a fruitful scientific concept, engaged in an axiological axis, to the extent that it can be transformed in spite of its resistance.

I am tempted to expand here on an inkling of Canguilhem's namely that, when Bachelard finally seeks to characterize the broad image of his historicist structuralism, he does so in unmistakenly biological terms, such as mutation, élan vital, etc....[38] And indeed, it is difficult to overlook the peculiar image of a concept in Bachelard, which somehow, in spite of itself, prompts its own deformation, and shows its use and longevity in its ability to overcome these challenges through successful deformation. A good concept overcomes its earlier, vague, imaginative, intuitive content, but does so because of the virtues of that content, virtues in its capacity to prompt and undergo deformation. A Bachelardian concept is valued in the same way as a Canguilhemian organism: by its capacity to overcome its current norms, but its capacity to adapt, to create a new norm for itself, by its plasticity and capacity to deformation in order to remain alive. Like a Canguilhemian organism, a Bachelardian concept is one that persists to the extent that it can balance its robustness with its adaptiveness, such that the latter is always not just in spite of, but also for the sake of the former.

As Ferdinand Gonseth, philosophical fellow traveler to Bachelard, once wrote: "a living concept cannot be created at once by a merely verbal definition, but emerges from its past and is modified by its use”[39] Gonseth stresses the notion of “living,” seemingly aware of the organic connotations of the properties he is ascribing to a concept, and thereby, once again, resonating with Bachelard’s metaphors. These metaphors, then, are not superficial, but instead express something essential about the theory of conceptualization we find in these authors. It could be worth it to prompt these concepts, and their as yet but metaphorical imagery, to become more precise, and to be deformed. One way to do so may be through a different interpretation of the meaning of an axiom. Gonseth, after all, continued the passage I just quoted with the following remark:

> Of the extent to which a word can veer away from its original sense bit by bit, the extent to which the concept that it covers can vary by imperceptible degrees and at times by sudden jumps, the word axiom is right now a striking example.[40]

I believe the word axiom is a striking example precisely because it evolved from the concept of that which stipulates, for now until eternity, the meanings and interactions of concepts, to a concept that is at the heart of a dynamical picture of concepts and conceptualization. As I remarked in the second section of this paper, Hilbert thought of the axiomatic method as comprised of two movements: one that deduces results from the basis axioms in the old style, and one that deepens the basis by seeking to unify and generalize. In this paper, I have sought to show that Bachelard saw the potential of the second movement as one of the motors of the process of conceptualization. It is this process which opens up concepts, articulates their simple states by increasing their relations with each other, by interdefining them to a greater and greater extent. But I have also wanted to suggest that the process of conceptualization is therefore also the process whereby concepts persist through scientific change by changing in this way. This is not a paradox, as Bachelard admitted in his early *Essai sur la connaissance approchée* that concepts are marked by *plasticity*:

> There are in the life of the mind moments that leave indelible traces, elements that nothing, it seems, could rectify: such are concepts. Of course, certain concepts that reveal themselves to be perfectly inadequate can disappear altogether, but they cannot fold to express as yet an experience that no longer supports them.
>
> But these solidly fixed elements present themselves at the summit of the process of conceptualization. If we could penetrate into the dust

> of minor concepts that spring immediately from sensation, we would see their fundamental plastic character.[41]

Bachelard rejects the idea that concepts are fixed, and thereby also rejects the idea that they either persist unchanged or disappear altogether. This idea that concepts need to remain fixed to persist is the fundamental idea that lies behind both anti-historical perspectives and historical perspectives that insist on relativism and incommensurability: any change in the meaning of the concept would imply that we are, in fact, dealing with another concept.[42] To Bachelard, this is wrong: concepts are dynamical in nature, and can persist through change. It is this very plasticity that can allow them to persist while theories, paradigms, epistemes, etc. change around them. Of course, some die out, some fail to persist, but those that do, do so not just because they have overcome the obstacles thrown at them by recalcitrant experience or theoretical change, but rather because they pre-empted the latter by their internal impulse for complication, and have overcome the internal obstacles that lead them to avoid deformation, all while maintaining enough of their identity. The new scientific spirit, for Bachelard, is one that recognizes this change and participates in the elaboration of concepts. Such a dynamic picture of concepts can maintain continuity and rationality in the face of historicity.

That Bachelard's philosophy is, in this manner, a philosophy of concepts, does not mean that he ultimately falls prey to the atavistic positivism that is often criticized in his name. This judgment is based on the idea that all aspects of such a theory are ultimately hazardous to understanding discontinuity, technology and the social in science. Rather, Bachelard's specific way to focus on concepts may help overcome some of the tensions to which attention to discontinuity, technology and the social have given rise. For one, Hans Radder has expressed concern over the tendency among some philosophers of experiment to regard concepts as local to experiments, and suggests that the non-locality of theoretical concepts is what allows them to have "'unintended consequences' that might arise from their potential use in novel situations"[43]. Bachelard's philosophy of concepts as persisting through deformation and suggesting unsuspected possibilities might be crucial to understanding how, for him, experiment has an "instructive" role in science. Secondly, this picture of Bachelard's philosophy of concepts might aid in some of the problems his discontinuist picture raises for the dialogue between history of science and philosophy of science, as has been recognized by Christina Chimisso:

> Bachelard's view of history of science [...] seems to leave little space for narratives that are not those 'sanctioned' by current science and that link present science with lapsed doctrines. It also interdicts long narratives, as science for Bachelard has only begun at the end of the eighteenth-century.[44]

On my interpretation, Bachelard ultimately allows for some continuity between the different deformations of the same concept, and ascribes to conceptual reflection some transformative role in science. In this way, his picture allows for a more positive role of history of science in philosophy of science than one would expect. The actuality of Bachelard thereby seems to consist in the opportunity he allowed for a philosophy of science that pays equal attention to all dimensions of science and integrates the various approaches to the sciences in a relation that he might have preferred to call dialectical.

NOTES

1. Bruno Latour & Steve Woolgar (1986). *Laboratory Life. The Construction of Scientific Facts*. Princeton, New Jersey: Princeton University Press, p. 258.
2. Dominique Lecourt (1975). *Pour une Critique de l'épistémologie* (*Bachelard, Canguilhem, Foucault*. Paris : François Maspero, p. 83.
3. For an account that stresses the revolt against continuism as central to Bachelard's thinking, see Dominique Lecour (1972). *Marxism and Epistemology*, trans. Ben Brewster. London: NLB, p. 22.
4. Gaston Bachelard (2011). *La formation de l'esprit scientifique*. Paris: Vrin, p. 74. All translations of quotes from Bachelard are mine.
5. Gaston Bachelard (1966). *Le rationalisme appliqué* (3rd ed). Paris : Presses Universitaires de France, p.125.
6. Lacourt, *Marxism and Epistemology*, p. 83.
7. For a sustained historiographical reconstruction of the Aristotelian Model of Science, see Willem R. de Jong & Arianna Betti (2010). "The Classical Model of Science: a millennia-old model of scientific rationality," *Synthese* 174: pp. 185-203.
8. For an extensive treatment of the partial rejection of Aristotle's axiomatic method in the Early Modern period of philosophy, see Boris Demarest (2013) "From the More Geometrico to the More Algebraico: D'Alembert and the Enlightenment's Transformation of Systematic Order," *Philosophica* 88: pp. 71-102.
9. Cf. Francis Bacon's *Instauratio Magna* in (1975). *The Works of Francis Bacon vol. 4*, edited by James Spedding, Robert Leslie Ellis & Douglas Denon Heath. London: Longmans, p.50.
10. Bachelard, *Formation*, p. 76.
11. Bachelard is in all likelihood thinking of the equally heteroclite—to the modern eye—"table of essence and presence" of heat to be found at Bacon, *Instauratio Magna*, pp. 127-129, as the main source of inspiration for such assortments of phenomena.
12. In the *Port Royal* Logique, Antoine Arnauld and Pierre Nicole explicitly cast doubt the Aristotelian evaluation of syllogistics in favor of conceptual clarity. Cf. Antoine Arnauld and Pierre Nicole. (1684). *La Logique ou l'art de penser* (5th ed.). Lyon: Mathieu Libéral, pp. 215-216.
13. Blaise Pascal, *De l'esprit géométrique*, in Victor Rocher (ed.) (1873) *Pensées de pascal publiées d'après le texte authentique et le seul vrai plan de l'auteur avec des notes philosophiques et théologiques et une notice biographique*. Tours : Alfred Mam, p.471.
14. John Locke (1975), *An Essay Concerning Human Understanding Locke, J.* (ed. Nidditch, P. H.). Oxford: Clarendon press, p. 671.
15. Immanuel Kant, *Jäsche Logik*, in (1992). *Lectures on Logic* (ed. & trans. Michael Young). Cambridge : Cambridge University Press, p.593.
16. In later developments in the history of logic, the validity of law has been called into question, of course (see for instance Clarence Irving Lewis (1918). *A Survey of Symbolic Logic*. Berkeley: University of California Press, p.322.
17. Pascal, *De l'esprit géométrique*, pp. 473-474.
18. David Hilbert, "Axiomatic Thought," in William Ewald (ed.) (1996). *From Kant to Hilbert: A Source Book in the Foundations of Mathematics* vol. 2. Oxford: Oxford University Press, pp. 1105-1115.
19. Hilbert, "Axiomatic Thought," pp. 1107-1108.
20. Hilbert, "Axiomatic Thought," p. 1108.

21. Hilbert, "Axiomatic Thought," p. 1108.
22. Hilbert, "Axiomatic Thought," pp. 1108-1109.
23. Hilbert, "Axiomatic Thought," p. 1115.
24. Hilbert, "Axiomatic Thought," p. 1109.
25. Hilbert, "Axiomatic Thought," pp. 1111-1112
26. David Hilbert (1950). *The Foundations of Geometry*, trans. E.J. Townsend. Lasalle: Open Court, p. 2.
27. Gaston Bachelard (1934). *Le nouvel Esprit Scientifique*. Paris : Presses Universitaires de France, p. 33.
28. Bachelard, *nouvel Esprit*, p. 27.
29. Bachelard, *nouvel Esprit*, p. 31, my stress.
30. Bachelard, *nouvel Esprit*, pp. 51-52.
31. Cf. Mary Tiles (1985). *Bachelard, Science and Objectivity*. Cambridge: Cambridge University Press, pp.145-146.
32. The role of late 19th century developments in mathematics and theoretical physics and their implications for the nature of concepts and for epistemological change figure in a similar way in Ernst Cassirer (1910) *Substanzbegriff und Funktionsbegriff*. Berlin: Bruno Cassirer Verlag. Both philosophers insist that the meaning of the basic of concepts of science change to more relational and functional and less "substantial." I am not sure whether this is due to a direct influence, and suspect rather that the influence of Brunschvicg on Bachelard made the latter sensitive to neo-Kantian ideas. In fact, there is a way in which Bachelard's approach, with its insistence on a productive role for the a priori, is still a neo-Kantian approach, and Bachelard himself admits that his non-kantism is not a rejection, but rather a rectification of Kant, in the same way in which the Marburger Schule considered itself to be a rectification of Kant informed by the development of science.
33. Bachelard, *nouvel Esprit*, p. 52
34. Bachelard, *Formation*, p. 74.
35. Gaston Bachelard (1940). *La Philosophie du Non*. Paris : Presses Universitaires de France, pp. 35-36.
36. Bachelard, *Philosophie du Non*, p. 138.
37. Bachelard, *Formation*, pp. 74-75.
38. Georges Canguilhem, "L'histoire des sciences dans l'oeuvre épistémologique de Gaston Bachelard," in (2015). Études d'histoire et de philosophie des sciences concernants les vivants et la vie. Paris: Vrin, p. 193.
39. Ferdinand Gonseth (1936). *Les mathématiques et la réalité : essai sur la méthode axiomatique*. Paris: Alcan, p. 236.
40. Gonseth, *mathématiques et réalité*, p. 236.
41. Gaston Bachelard (1928). *Essai sur la connaissance approchée*. Paris: Vrin, p. 17.
42. A more subtle version of this view, which can be discerned in Dominique Lecourt's work (cf. Lecourt, *Marxism and Epistemology*, pp. 84-86), is that the continuity is as it were retroactive: a new stage of science establishes retroactive continuity by projecting its own knowledge into the past, and assimilating its earlier stage into the former. Although one could reconstruct passages such as those on the relation between Euclidean and non-Euclidean geometry in this fashion, Stephen Gaukroger was right to insist that this does not square with all of Bachelard's comments on the persistence of concepts (cf. Stephen Gaukroger (1976). "Bachelard and the Problem of Epistemological Analysis." *Studies in the history and Philosophy of Science* 7(3), p. 234.). Of course,

Lecourt could regard these passages as atavistic but inessential, where Gaukroger regards them as essential and revealing of a central flaw. In this paper, I have attempted to offer a different appreciation, and regard this as Bachelard's actuality.
43. Hans Radder (2003). "Technology and Theory in Experimental Science," in Hans Radder (ed.) *The Philosophy of Scientific Experimentation*. Pittsburgh, Pa.: University of Pittsburgh Press, 158.
44. Christina Chimisso (2015). "Narrative and epistemology: Georges Canguilhem's concept of scientific ideology," Studies in History and Philosophy of Science 54, p.66.