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Justification, Creativity, and Discoverability in Science

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Serendipity between psychology and logic of scientific discovery

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Abstract. Serendipity is the phenomenon whereby a fortuitous and unexpected experience turns out to be an essential element leading to a scientific discovery or invention. The discussion of serendipity has led to the formulation of a "paradox of control": on the one hand, serendipitous discoveries are accidental and unpredictable, but on the other hand, they can be prepared and fostered. The paradox, already foreshadowed by Plato, brings to light the need to reconcile two essential elements of scientific discovery: unpredictability and genetic-methodological reconstructability. To resolve this paradox, it is appropriate to challenge both the acceptance of the Popperian (or neopositivist) distinction between psychology (or discovery) and logic (or justification) and its subsequent rejection within the epistemological tradition. This leads to a distinction between two senses—one reflexive, the other genetic-methodical—of the psychology/logic (or discovery/justification) dichotomy that resolves the paradox of serendipity. A critical analysis of Popper's considerations of accidental discoveries in science both clarifies more concretely the root of the paradox and to distinguish his eclectic solution from the one proposed here.

1 Introduction

Many philosophers of science have insisted on the complementarity, in science, of creative-subjective invention and methodological-objective justification. Karl Popper, for example, drew a well-known distinction between the psychology and the logic of knowledge, whose cooperation captures according to this author the very essence of scientific research. For him, science is characterized by two stages that, while in many logical senses opposite and chronologically distinct, are both necessary: the first characterized by an act of creative intuition, the second by the critical-methodical effort to check and falsify the products of that intuition.

A similar distinction is to be found in Henri Poincaré. He found in mathematics two entirely different kinds of minds: the "logicians" (*logiciens*) and the "intuitionalists" (*intuitifs*). The one group places logic in the foreground, leaving nothing to chance, the other group resorts first and foremost to intuition (Poincaré 1906, pp. 11–16, Engl. Transl. pp. 210–222). He, too, recognized the need for cooperation between these opposing attitudes of thought, emphasizing both the importance of preparation and accuracy in the formulation of a problem, in order to facilitate the next moment of creative invention, and the shortcomings of a purely logical-demonstrative

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procedure: "logic is not enough; [...] the science of demonstration is not all science and [...] intuition must retain its role as complement, I was about to say as counterpoise or as antidote of logic."[1]

Now, the problem underlying these and many other similar positions is that, on the one hand, creativity and method are two concepts that are both necessary for understanding scientific discovery, but, on the other hand, they, at least at first glance, seem mutually exclusive. It is precisely this complementarity and tension between the two concepts that has recently been taken up in the discussion around serendipity, i.e., the phenomenon in which a fortuitous and unexpected experience turns out to be an essential element leading to a scientific discovery. Within this discussion, in fact, a "paradox of control" has been formulated, according to which, on the one hand, serendipitous discoveries are accidental and unpredictable, but, on the other hand, they can be prepared and learned by an appropriate method. As we shall see, to resolve the tension between these concepts, it is necessary to rethink the relationship between creativity and method in scientific discovery or, more generally, the traditional distinction between psychology and logic, between the context of discovery and the context of justification. In this paper I shall try to resolve this paradox by showing that, by more adequately analyzing these pairs of concepts, it is possible to distinguish two senses—one reflexive (or transcendental), the other genetic-methodological—in which they can be understood. The two different points of view from which the concepts of creativity and method can be considered show that, far from being opposites or even antinomic, these concepts are complementary, such that each requires the other as its logical complement. For this purpose, however, creative invention and critical-methodical control should not be understood—as is the case of Popper (or of the logical empiricists or of Kuhn's endless cycle of normal and revolutionary phases)—as two separate components or phases of scientific research, which could exist and stand, as it were, separately side by side. Instead, the two concepts are never given separately from each other and can be distinguished only by counterfactual abstraction. Creative unpredictability and genetic-methodological controllability are two inseparable faces of the same concrete cognitive act. Creativity tends to resolve itself into the elaboration of particular scientific methods, which in turn redeem and transform the unpredictability (or "accidentality") of

[1] Poincaré 1906, p. 25; Engl. Translation, p. 35; on this point see also Poincaré 1908. Many later authors were inspired by Poincaré. G. Wallas, for example, was influenced by Poincaré in his proposal of the following four stages of creative thinking: "Preparation, Incubation, Illumination (and its accompaniments), and Verification" (cf. Wallas 1926, pp. 79–107). Poincaré's basic idea was also taken up by Campbell 1960, who interpreted it as favouring a blind-variation-and-selective-survival process for understanding all genuine increases in knowledge: cf. Campbell 1960, pp. 215–218 and 282–311.

the serendipitous event into a methodological path that is in principle reconstructible and intersubjectively controllable.

2 The concept of serendipity and the paradox of discovery

The English word "serendipity" was coined in 1754 by Horace Walpole on the basis of a fairy tale about "The Three Princes of Serendip" (the old name of the island of Ceylon), who, as he wrote in a letter to Horace Mann,

> were always making discoveries by accident or sagacity of things they were not in quest of: for instance, one of them discovered that a mule blind of the right eye had travelled the same road lately, because the grass was eaten only on the left side, where it was worse than on the right (Walpole 1754, pp. 407–408).

The most important milestone in the analysis of the concept is Merton and Barber's initially unpublished draft *The Travels and Adventures of Serendipity. A Study in Historical Semantics and the Sociology of Science*, dated 1958. Reworking and publication of this unpublished draft gave the final and decisive impulse to the fortune of the term in many fields of research, including that of the philosophy of science: first published in Italian translation in 2002, the work was followed two years later by the English edition in Merton and Barber 2004.[2]

Merton's two fundamental ingredients, unexpected and fortunate findings on the one hand and insight or wisdom on the other, return, with some variations, in almost all subsequent definitions. This applies not only to the definitions more often proposed within the epistemological debate (cf., e.g., Van Andel 1994, p. 643; Fine & Deegan 1996, pp. 434 and 445; McBirnie 2008, p. 604; Thagard 1998a and 1998b; Nickles 2009, pp. 179 ff.; Copeland 2019, p. 2386; Arfini, Bertolotti and Magnani 2020, p. 940 fn.), but also to those concerning more particular areas of research, such as information seeking, management, innovation, or recommender systems.[3] In fact, the number of works devoted to serendipity today seems to be increasingly concentrated in the latter areas (cf. Quy Khuc 2022), but in all of these

[2]Merton, however, had analyzed the concept of serendipity in works prior to the just mentioned draft. In his essay *Sociological Theory* (1945, p. 469n.), he already gave a concise definition of the phenomenon: "Fruitful empirical research not only tests theoretically derived hypotheses; it also originates new hypotheses. This might be termed the "serendipity component of research, i.e., the discovery, by chance or sagacity, of valid results which were not sought for" (Merton 1945, p. 469n.; the definition has been taken up both in Merton 1948, p. 506 and in Merton 1949, p. 98).

[3]For information seeking see e.g. Case 2007 (p. 337), Foster & Ellis 2014, and the important empirical study by Sun et al 2011. For management and innovation, see e.g. MacDonald 1998, De Rond 2005, Gherardi 2006, Fink et al 2017, and Busch 2022. For recommender systems, see e.g. Kotkov, Medlar and Glowacka 2023.

publications there is a clear need to first establish a general definition before embarking on specific investigations, which indirectly shows the need for a properly philosophical analysis of the concept, the sole object of this paper.

The main problem associated with the concept of serendipity is that the two main characteristics indicated by Merton are not easily reconciled and, indeed, that we are dealing with a paradoxical, if not oxymoronic or contradictory concept. The first to intuit this was Horace Mann, Walpole's correspondent. Mann not only directly relates the term "serendipity" to scientific research (which was not the case in the letter sent to him by Walpole), but also, indirectly, raises the problem we intend to discuss here, the tension between the accidentality and unpredictability of discovery on the one hand and the necessity of its intersubjective or methodological reconstructability on the other. Mann noted that the type of serendipity with which Walpole was endowed is very peculiar: not only does accidentality appear in it, but this accidentality is such that, once the "serendipitous" event is given, it universally leads to the discovery itself:

> I perfectly understand your 'serendipity'. It must have happened to everybody, that in searching for one thing, others of greater importance have occurred. How many useful discoveries, for example, has the search of the philosopher's stone produced, that the student was certainly not in quest of. Is not this 'serendipity'? But the *sortes Walpolianae* are still more useful, if you can find everything *a point nommé* whenever you dip for it. (Mann 1754, p. 415)

The problem raised by serendipity had emerged since the early days of philosophical thought. In 1994, Van Andel aptly called attention both to the paradoxicality of the concept of serendipity and to the relevance of well-known classical problems in the serendipity debate, choosing two significant exergues: a fragment of Heraclitus and Plato's eristic argument posed by Meno. The Heraclitus fragment is as follows:

> If you do not expect the unexpected, you will not find it; for it is hard to be searched out and difficult to compass.[4]

[4]Heraclitus, Fr. DK B 18, a fragment, however, which I quote from Marcovich's 1967 translation, p. 40. This translation seems preferable to me because it expresses the extreme difficulty, but not the impossibility, of finding the unexpected. Marcovich's translation, in fact, takes into account the fact that ἀνεξερεύνητον "mean[s] only 'hard to be searched out' and 'difficult to compass or discover', and not 'impossible to . . .'." The Logos, the author points out, "is 'difficult to compass' either because it is hidden inside the things or because it is paradoxical" (Marcovich 1967, p. 40). Cf. also Kirk, Raven, and Schofield 1983, p. 193: "If one does not expect the unexpected one will not find it out, since it is not to be searched out, and difficult to compass." Cf. also Mason 2014, p. 68, fn. 18: "If one does not expect the unexpected one will not discover it, for it is not to be discovered and intractable".

Here the problem that is inherent to the concept of serendipity is formulated indirectly, with respect to the aim of discovering the ultimate essence of reality: does it make sense to expect the unexpected? According to Heraclitus, the answer is in the last analysis affirmative, though with an important *caveat*. However difficult to grasp, the *Logos*, which is the least familiar and least expected one can conceive, allows one to decipher, and thus expect, what is "indicated by signs", but not explicitly told, by the gods to men: the oracle in Delphi, in Heraclitus' own words, "neither speaks out nor conceals, but gives a sign." (Heraclitus Fr. DK B 93, transl. from Marcovich 1967, p. 51).

Later—as Van Andel 1994's second exergue rightly suggests—the problem will be re-proposed in the famous eristic argument formulated in Plato's Meno, according to which it is impossible for man to investigate both what s/he already knows and what s/he does not yet know:

> SOCRATES: I know what you want to say, Meno. [...] a man [...] cannot search for what he knows – since he knows it, there is no need to search – nor for what he does not know, for he does not know what to look for. (Meno 80 e; Engl. Transl. by G. M. A. Grube, in Plato 1997, p. 889)

If we leave aside the explicit use of the term "serendipity," it was in my opinion Thomas Nickles, in his numerous and always enlightening contributions concerning the concept of scientific discovery, who gave a striking formulation of the paradoxical character of serendipity. On the one hand, he wrote, "any method capable of generating interesting, new knowledge must incorporate an element of luck, chance, or contingency." (Nickles 2009, p. 179) But, on the other hand, "the idea that there could be a method of innovation based upon luck or chance or serendipity looks positively oxymoronic. Chance and luck are the very things that method traditionally is supposed to exclude." (Nickles 2009, p. 178)

As for finally the more recent discussion of this problem under the name of serendipity, Abigail McBirnie gave the most explicit formulation of a "paradox of control" inherent in the concept of "seeking serendipity": "[w]hile seeking serendipity seems improbable, paradoxically, some degree of control may be possible." (McBirnie 2008, p. 601) As the author explains, the paradox arises from the combination of, on the one hand, the "random, elusive and unpredictable nature" of serendipity, which seems to rule out any attempt to pursue it, and, on the other hand, method, "which suggests a purposive approach and a skill or ability that 'can be trained and encouraged'" (McBirnie 2008, p. 604).

How to solve the paradox of serendipity and, more generally, of discovery? The Platonic solution was only apparent or circular. The hypothesis according to which we bring back to memory something we have already

known in a pre-birth life, when the mind's eye was not obscured by sensible appearances, merely shifts the problem from our embodied existence to that, even much less known, of a purely intellectual existence preceding our present, embodied one. How could we, in pre-birth life, have known new things (that is, "ideas")? What remains unexplained is precisely the possibility of discovery of new intelligible ideas of the *hyperouranios topos*.

But what about the solutions proposed in the serendipity debate? Sometimes they move in the right direction, but are not entirely satisfactory. Their most frequent flaw is that, instead of explaining at the root the coexistence of chance and method, they insist on the fact of this coexistence and make it plausible by resorting to concrete examples in which both elements are present. However, to simply insist that, despite the accidentality and unpredictability of serendipitous discovery, it is possible to foster unexpected discoveries is, in the final analysis, like refuting Zeno's arguments against the existence of movement by walking back and forth.[5]

Now, to outline how the seemingly opposite elements of serendipity can be conceived without falling into paradox, it is necessary to make a small detour, briefly addressing the problem that, in my view, lies at the heart of the paradox: the way of understanding the relationship (in Popper's lexicon) between the logic and the psychology of knowledge, or (in the lexicon of logical empiricists), the relationship between the context of discovery and the context of justification. For reasons of space, I will say only the minimum necessary to outline the solution of the serendipity paradox.

3 Two fundamental senses of the psychology/logic (and discovery/justification) distinction

The distinction between the psychology and the logic of knowledge is both one of the main pillars of Popper's philosophy of science and a point that, despite other differences, he shared essentially with the logical empiricist philosophy of science:

> I shall distinguish sharply between the process of conceiving a new idea, and the methods and results of examining it logically. [...]

[5]To this general claim (which applies above all to the essays oriented towards the search for concrete applications, as in the case of the literature focussing on information seeking or management) there are some notable, but partial exceptions, which would deserve a separate discussion, a task quite beyond the limits of this paper. See for example Nickles 2009, Catellin 2014, Arfini, Bertolotti, Magnani 2020; Glăveanu 2022, Copeland 2019, 2022, and 2023. These authors certainly move in the same direction of this paper. But there remains an important point of disagreement with them, which can be briefly summarized as follows: they do not draw a sufficiently neat distinction between the two fundamental senses in which, as we shall see, Popper's psychology/logic dichotomy (or the neopositivistic discovery/justification corresponding one) must be understood in order to resolve the serendipity paradox.

> [T]here is no such thing as a logical method of having new ideas, or a logical reconstruction of this process. [...] From a new idea, put up tentatively, and not yet justified in any way [...] conclusions are drawn by means of logical deduction. These conclusions are then compared with one another and with other relevant statements, so as to find what logical relations (such as equivalence, derivability, compatibility, or incompatibility) exist between them. (Popper 1935, pp. 4–6; quotations from the Engl. Transl., pp. 8–9)

In this way, Popper essentially took up the distinction discovery/justification that the logical empiricist philosophy of science had drawn (for historical details on this distinction, see Schickore and Steinle (eds) 2009, above all Part I and Part II, and Buzzoni 2015).

In general, the logical empiricists and Popper used the distinction to grant empirical science cognitive autonomy vis-à-vis the wider cultural and historical context. This was one of the reasons that the exponents of the relativistic philosophies of science of the 1960s (especially Kuhn and Feyerabend) and the advocates of the sociological turn (notably Bloor and Latour) from the 1980s onwards rejected the distinction in question. According to Kuhn and Feyerabend, for example, merely because they played an historical-causal role in the scientific process, *empirical-historical factors* such as scientists' prejudices and personal idiosyncrasies, aesthetic preferences, religious beliefs etc., are to be put on a par with more traditional *reasons* for maintaining or rejecting a theory, such as coherence, explanatory scope, unifying power, etc. (cf. Feyerabend 1970, § 14; Kuhn 1962, pp. 151–156; for an exponent of the sociological turn, see e.g. Bloor 1991, pp. 36–37).

In this way, however, the baby was thrown out with the bathwater. The baby was the minimal sense that I shall call here *reflexive-transcendental* (or simply *reflexive*) and in which reason is irreducible to empirical, particular causal factors, that is, as an expression of its claim to represent, in principle, things as they really are (no matter how far this can succeed). Although a countless number of physical, biological, psychological, sociological, and, generally, contingent or accidental factors influence and limit human reason, the irreducibility of this latter, at least in a sense, cannot be denied without denying all possibility of meaningful thinking or talking. Any claim to reduce reason to causal factors, necessarily presupposing its own truth, is irreducible to the causal factors to which, contradictorily, it grants a determining power over itself. In fact, to assert any empirical fact is to assert, implicitly, the distinction in principle between reason and facts, without which there would be neither one's own asserting nor one's own denying. At least in this sense the distinction between the contexts of justification and discovery is constitutive of reason and cannot be denied without contradiction, since it is affirmed by the very act of negating it.

So far I have defended the distinction in principle between psychology and logic of knowledge (or between context of justification and context of discovery) in the reflexive-transcendental sense, which expresses the irreducible autonomy of reason. However, we should distinguish at least another sense, which I shall call *genetic-methodological*, which is the opposite complementary of the reflexive-transcendental just seen, a sense in which this distinction must be entirely rejected.[6]

In fact, if the general claim of representing things as they are is not to remain devoid of any particular content and cognitive function, it must be realized by means of concrete methodological procedures which make it possible to reconstruct, to re-appropriate and to evaluate in the first person the reasons why a particular truth-claim should be accepted. In other words, the truth-claim of our discourses tends by its very nature – and more precisely as subordinate to the goal (in itself normative) of establishing itself as true – to translate (in principle without residue) into particular methods (or techniques).

Not only the logical empiricists, Popper and Lakatos, but also the exponents of the relativistic and sociological turn, failed to clearly identify this sense, in which a genetic-methodological (or genetic-historical) attitude is decisive for justification. To test the truth value of a statement, in principle we must always adopt this genetic and historical-reconstructive attitude and retrace the main methodological steps taken by those who first achieved a certain result through those steps. Pythagoras's Theorem can be used in a practical way without recalling the procedural steps of its demonstration. But if someone challenged its validity, we ought to test it by retracing in the first person the procedural steps that led to that theorem being asserted. By doing this, we *justify* a theory by historically reconstructing the context of its *discovery*. In this sense, context of discovery and context of justification are one and the same thing (for a more detailed justification of this thesis, see Buzzoni 1982 (ch. 3, § 1 and passim), 1986 (ch. 2 and *passim*), 2008 (ch. 1, §§ 4–7), and 2015).

4 Serendipity between psychology and logic of scientific discovery

The distinction between two senses – one reflexive, the other methodological (or genetic-methodological)—of the distinction between psychology and logic (or discovery and justification) of scientific knowledge allows to better understand and resolve the riddle of serendipity. As we have seen, on the

[6]Hoyningen-Huene 1987 carefully analyzes several senses of the discovery/justification distinction, but while these distinctions are certainly useful in particular contexts, none of them coincides with the one I have developed since Buzzoni 1982 and which is essential to defending the unity and distinction between creative invention and method in the sense of the central thesis of this paper.

one hand, if understood as an expression of the inescapable autonomy of the logical-discursive level of representation, the distinction between the logic and the psychology of knowledge must be maintained. The irreducibility of the rational value of our assertions about the world expresses the reflexive (or transcendental) dimension of discovery or invention, the ultimate source underlying all creativity, all emergence of what is new. This, on closer inspection, is also the point made by Popper against what he calls "historicism" by an argument that, though concerning the general growth of scientific knowledge, applies, *mutatis mutandis*, to the more limited growth of knowledge to be found in a single new discovery: "We cannot predict, by rational or scientific methods, the future growth of our scientific knowledge", since this would be tantamount to already knowing today what we will only know tomorrow (cf. Popper 1957, p. ix–x).

The argument holds that one cannot suppress the character of unpredictability (and/or chance, in a sense still to be clarified) that accompanies not only discoveries usually considered paradigmatic of serendipity, but any discovery as such. Every new idea has two sides, distinct but inextricably connected: on the one hand, as an expression of our rationality in its reflexive-transcendental sense examined above, it is, in a purely formal sense, an absolute beginning that cannot be reduced to actual causal factors. However, each new idea, while not predictable, can be satisfactorily explained ex post, after it has materialised in particular contents, drawn from experience or the world of culture.

In other words, even if from the transcendental point of view rationality is in principle absolute and free from conditioning, it is nevertheless, and indeed precisely because of this, entirely conditioned on the side of content. As we have seen, the inescapable sense in which human reason claims its autonomy is specifically realized in the process of knowledge through a particular set of methods, that is, etymologically, of retraceable "ways" or "paths," without the indication of which the fundamental scientific value of intersubjective controllability would be lost. This is the case because, however formally absolute, scientific creativity is in principle nevertheless subordinated to the personal commitment of the scientist to witness how things are in themselves, seeking to bracket any subjective biases or idiosyncrasies towards the object. Now, concretely, this commitment is realized precisely in putting in place a series of methods or procedures that, in principle, must be traceable and reconstructible by anyone in the first person and must lead to the ascertainment of actual courses of events independent of our subjective will.

This stems from the complementarity between the reflexive level of creativity and the genetic-methodological level of the principled reconstructability of any scientific discovery. Finding a question that the event we have stumbled upon provides an answer to, is not something that could have been

predicted (at least in its determinacy) before it actually occurred—which is why we consider it a "creative" performance of the human mind—but, in light of the preceding considerations, it must be to some extent reconstructible (and thus to some extent comprehensible and predictable) after the discovery has occurred, and precisely on the basis of the methodical steps that, starting from the initial accidental event, led—and can in principle lead again any agent endowed with mind and body—to the discovery itself. Serendipity, considered in this light, is a particular example of a general phenomenon, which consists in the possibility of inserting *any* actual event already happened into a rational-explanatory discourse, i.e., one endowed with intelligible and intersubjectively testable meaning. What was previously accidental and fortuitous for us disappears as such and becomes a step in the genetic reconstruction of the demonstrative-experimental procedure that led to the discovery.

To better explain this last point, the account of thought experiments I have developed elsewhere proves to be an important aid. According to my account, one of the most general conditions of the possibility of formulating thought experiments lies in the typical capacity of human reason to transform any data or empirical circumstance into something that is hypothetically counterfactual, and only insofar as it can be thought or imagined as such, it can be inserted into the meaningful whole of our discourses, and more generally, into the meaningful whole of human culture. The ability to give new meaning to facts already known from experience, placing them in a new counterfactual context, is ultimately the same capacity that underlies our ability to experiment in thought.

This is true of the simplest perceptions. I am only able to perceive the red of a rose because I can hypothetically and counterfactually assume the possibility that it is of any other colour, and then reject this possibility on the basis of my empirical perceptions. Even a declarative sentence like "the sun is shining" has meaning only against the background of the possibility that the sun might not be shining. This sentence expresses an empirical observation that is the answer to a cognitive question concerning a hypothesis about the state of the sun; without this hypothesis, which usually remains in the background and is not explicitly addressed, the observation that the sun is shining would have no definite meaning. But this is also true in general. To be able to formulate thought experiments is the condition of possibility to conceive of, and then execute, real world experiments (for more details on this point, see Buzzoni 2008, pp. 115–116).

In the capacity to imagine things as something different from what they actually are lies the first condition of the unpredictability of human discoveries: we cannot place an a priori limit on finding new and different ways of looking at reality. In its properly transcendental sense, the distinction

between the rational context of justification and the historical context of discovery is not only irreducible (in the sense that the rational value of our assertions is irreducible to any set of historical factors or circumstances), but also allows us to grasp the transcendental value of discovery or invention in itself, the true nature of the creativity that underlies every emergence of what is new. The first condition for an accidental event to be included in the conceptual path of a discovery is that it is assumed to be a purely hypothetical or counterfactual event. Without this, both simple observations and real experiments would be, strictly speaking, unintelligible. Tackling the problem under this perspective, the mind's ability to imagine counterfactual scenarios, the ability to see things differently from how they actually are, makes any experience, including "accidental" ones, a plausible answer to hypothetical questions that we are able to formulate. From this point of view, events that are accidental (and as such not only unplanned, but also independent of us) become parts of a thought experiment, which may lead to a scientific discovery. Empirical discoveries always move from contingent conditions and end with the formulation of some new question to which those conditions, now transformed into parts of the counterfactual scenario of a thought experiment, can be regarded not as the first, but the last elements of a chain of events that provides an intersubjectively reproducible and therefore testable answer.

This is more than the usual claim of the unpredictability and freedom of scientific research, so far as we are in a position to avoid the risk of assuming only one of the two fundamental aspects of serendipity (the reflexive-transcendental one), and neglecting the other (the genetic-methodological). The mentioned risk is avoided from the outset by the complementarity – the key concept in our explanation of serendipity – of the reflexive-transcendental level of creativity and the genetic-methodological level of the intersubjective testability in principle of every concept. As already seen, if the reflexive-transcendental claim to represent, in principle, things as they really are is not to remain devoid of any particular content and cognitive function, it must be realized by means of genetic-methodological procedures, which make it possible to genetically reconstruct, to re-appropriate and to evaluate in the first person the reasons why a particular truth-claim should be accepted.

Some examples can illustrate what we have been saying. Consider first a simple example taken from everyday life. I notice a stone in my path. Is it simply an obstacle, because it might be something I might stumble upon? Or does its shape suggest to me (perhaps because of some affordances in Gibson's sense) that I can use it as a scraper to sharpen other tools? In one sense it is certainly true that the answer will certainly depend, in its specificity, on my prior "background knowledge" (Popper), acquired habits, etc. But, if one does not neglect the properly reflexive-transcendental side of

the problem, this will always also depend on the human capacity to interpret what one sees (a stone in my path) as a plausible answer to a hypothetical question that has arisen in the course of our interaction with the world around us (for example: "How could I make sharper arrowheads?").

Thus, finding a question to which the event we stumbled upon provides an answer is not something that could have been foreseen at a time before it happened, both because it concerns a real event independent of human will, and because our explanation was not univocally predetermined a priori. Nevertheless it must now be reproducible (and therefore comprehensible and predictable) after the discovery has taken place, and precisely on the basis of the methodological steps that, starting from the initial accidental event, have led – and can in principle lead – to the discovery itself.

Now, in the same way, we must treat the cases most clearly related to serendipity. Note first that the same facts that for other people were purely accidental—and therefore inexplicable—for the three Principles of Serendipity were the logical and at the same time practically reconstructible consequences of their reasoning. But let us look at historically real examples. Take for instance Fleming's discovery of penicillin, one of the most cited and investigated examples of serendipity. As well known, Fleming observed that in a culture plate, accidentally contaminated by a mould, the bacterial growth of Staphylococcus colonies was inhibited. Many accidental factors favoured the discovery, which – as has been noted – were due to several concomitant circumstances, some of which had an exceptionally low probability of occurrence even when taken in isolation: the poor tidiness in the laboratory, very particular bacteria that had colonised the Petri dish, the weather conditions, and many others as well (cf. Waller 2002, pp. 251–255). However, if we reconstructed in detail what happened to Fleming from the first fortuitous co-occurrences to his discovery, we would find exactly what he found. Even the initial accidental events are no longer pure coincidences, but the initial moments of a mental and at the same time practical-experimental pathway that we can still retrace now. As we can see, the principle of genetic-methodological reconstructability is also respected in this kind of discovery, which is paradigmatic of serendipity.

The same applies to the classic Newtonian apple, which became an example of the (hypothetical) law of universal gravitation. The first fall was accidental (both in the sense of being a real event independent of human will and in the sense of not being foreseeable on the basis of the knowledge of the time), but the place it later occupies, both in Newton's first explanation and in the explanation we can give today, is well determined. Or take Semmelweis's discovery of the cause of puerperal ("childbed") fever: nursing mothers who were in the ward and therefore not accessible to doctors who had previously handled corpses did not fall ill by pure chance. Since the

aetiology of puerperal fever had not yet been discovered, there was no reason why some women fell ill and others did not. But this case, when translated into genetic-methodological rationality, became in principle a technically reproducible effect, generating the rule not to visit women who had given birth without first washing hands thoroughly. Also the initial, accidental and contingent moments of discovery can always, in principle, be reconstructed rationally.

In all these cases, from the new point of view, an event formerly serendipitous (and inexplicable except by means of the mind's freedom to construct possible counterfactual courses of events), is now no longer so, unless we move our minds into the past, before it took place, before the mind constructed a counterfactual course from which it is now possible to represent in the mind a series of events ending with the very fact from which the mind itself had started in its explanatory effort.

In the next section, we shall briefly examine the way in which Karl R. Popper, without using the term serendipity, addressed the role of chance in scientific discovery. As I shall try to show, it is precisely Popper's inability to grasp the sense in which it is necessary to distinguish, alongside the transcendental-reflexive sense of human reason, a genetic-methodological sense, which prevented him from going beyond an eclectic position, not essentially better than the psychological considerations of Pasteur.

5 Popper and accidental discoveries in science

Like other authors, Popper insists that, in spite of its unexpected and accidental character, every discovery presupposes a mind prepared to exploit this chance. As is well known, according to Popper, no empirical finding can count as a discovery if it does not acquire its meaning from the point of view of a theoretical expectation that we seek to refute (and which is part of a background knowledge, without which research could not advance one step). From this point of view, and bearing in mind Popper's equation between the information content of a theory and its improbability, it is no surprise that Popper provided *ante litteram* a relatively simple answer to the problem of the serendipitous character of scientific discoveries.

According to the fundamental methodological rule of Popper's falsificationism, we ought to test our most cherished theoretical hypotheses in order to falsify them, and we can only accept them as corroborated if this corroboration somehow surprises us and makes us see that, even if we thought our hypothesis was false, against all probability it has withstood our best checks. According to Popper, in fact, the empirical content of a scientific theory is the greater the more improbable the theory is: the more a scientific hypothesis says about the real world, the greater its empirical content, the greater the number of its potential falsifiers, i.e., the imaginable circum-

stances in which it could be falsified. Or, correlatively, the more a scientific hypothesis says about the real world, the less likely it is to be corroborated. Here, the (partially) accidental nature of corroboration is reconciled, at least at first sight, with the need to have both a hypothesis that makes sense for future observations and all the experimental preparation necessary to put the theory to the test:

> Lavoisier's experiments were carefully thought out; but even most so-called 'chance-discoveries' are fundamentally of the same logical structure. For these so-called 'chance-discoveries' are as a rule refutations of theories which were consciously or unconsciously held: they are made when some of our expectations (based upon these theories) are unexpectedly disappointed. Thus the catalytic property of mercury was discovered when it was accidentally found that in its presence a chemical reaction had been speeded up which had not been expected to be influenced by mercury. But neither Örsted's [*sic!*] nor Röntgen's nor Becquerel's nor Fleming's discoveries were really accidental, even though they had accidental components: every one of these men was searching for an effect of the kind he found. We can even say that some discoveries, such as Columbus' discovery of America, corroborate one theory (of the spherical earth) while refuting at the same time another (the theory of the size of the earth, and with it, of the nearest way to India); and that they were chance-discoveries to the extent to which they contradicted all expectations, and were not consciously undertaken as tests of those theories which they refuted. (Popper 1969, pp. 220–221).

Popper's answer is ultimately a version of Pasteur's oft-cited comment on Hans Christian Ørsted's discovery of the "electric telegraph": "in the fields of observation chance favours only prepared minds (*esprits préparés*)" (Pasteur 1854, p. 131). The accidentality of discovery is greatly attenuated by the scientist's degree of "preparation" or already acquired knowledge, which also attenuates the concomitant phenomenon of surprise, whereby, as Aristotle already noted, what surprises the ignorant does not surprise the knowledgeable (cf. *Met.* 983a 12–20).

The scientist's previous background knowledge, in fact, makes it possible to give theoretical meaning to observations that would otherwise remain devoid of any cognitive significance, even if, Popper adds, it must be admitted that neither Ørsted's nor Röntgen's nor Becquerel's nor Fleming's discoveries "were really accidental, *even though they had accidental components*".

Now, on closer inspection, Popper continually confuses the two senses in which it is possible to understand both the ('psychological') unpredictability and the ('logical') reconstructability of scientific discoveries.

On the one hand, he confuses two meanings of unpredictability: one is that which concerns the accidental event which, in hindsight, favours

discovery, but which is in itself a real event independent of our will; the other is that of discovery as a mental representation that makes a real event at first sight completely isolated fit into the web of causal relations already conceptualised. Now, while the latter sense is transcendental and cannot be predicted (as Popper rightly argued, we cannot have knowledge today of what we will know/discover tomorrow), the former is accidental and unpredictable only because of its independence of our subjective will. Strictly speaking, in fact, what is accidental in the sense of being unpredictable for us (in the light of our current knowledge) is, at least from a heuristic perspective, representable as potentially part of a determinate causal chain, which in fact, in the light of the discovery made, will be methodologically perfectly reconstructible.

In other words, any event that occurs without it being possible to indicate a reason why it occurs or does not occur is by definition accidental (like the number on the wheel of fortune or the number that comes up after rolling a dice), but as we discover other circumstances or conditions under which it occurred, it becomes more and more probable and our ignorance diminishes: it approaches asymptotically, often without ever being able to reach it, the limit value of a deterministic event. Lightning, which for primitives was so indeterminate as to be attributed to the capricious will of God, is today not only (largely, not entirely) predictable but, under certain experimental conditions, even reproducible in the laboratory.

In this case, however, the most important significance of accidentality is that it presupposes the existence of an external reality that is independent of our subjective will as far as its content is concerned. In this sense, accidentality is by no means paradoxical, but, on the contrary, is a condition of possibility of science as an enquiry concerning an independent reality. Nevertheless, this accidentality must be 'redeemed' in a different sense: the accidental event must be turned into an initial situation from which follow a series of steps leading, in an intersubjectively testable manner, to its explanation, i.e., to a discovery.

In addition to confusing two distinct concepts of the accidentality of scientific discovery, Popper also confuses two distinct concepts of the hypothetical moment. Popper (like Pasteur, Leibniz, and many other recent authors) is certainly right to argue that the first condition for an accidental event to be included in the conceptual path of a discovery is that it be thought of in the light of some particular hypothesis. But this very capacity to formulate particular hypotheses depends on the more radical capacity in general of the mind on which we insisted above. Unlike in Popper, this radically hypothetical character of science cannot be confused with the particular hypotheses that are formulated from time to time to understand our experience. Instead, the individual concrete hypotheses developed for this purpose are the way

in which the reflexive or transcendental side of serendipity is translated into concrete genetic-methodological steps. They only embody the methodical aspect of discovery, without which its reproducibility, its intersubjective controllability, in short its scientificity, would be lost.

In addition to particular hypotheses, one must distinguish the ability as such to counterfactually assume a hypothetical horizon that defines the space of meaning as such. The simplest observation of what reality is like presupposes that it can be hypothetically different. As already mentioned, I can perceive the red of the rose I am looking at only because I can hypothetically assume the possibility that it might have a different colour (and I can then reject this possibility on the basis of my empirical perceptions). This possibility, as a general possibility or capacity to formulate hypotheses (and not as a specific hypothesis), ultimately coincides with the mind's capacity to give cognitive meaning to the perceptual-real datum.

Popper's solution ultimately remains eclectic because of the confusion between the transcendental-reflexive meaning and the genetic-methodological meaning of the fundamental concepts he uses. More precisely, it is a double confusion because it concerns both the moment of accidentality as it relates to the moment of the "psychology of knowledge" and the moment of methodological reconstructability as it relates to the moment of the 'logic of knowledge'. Because of this double confusion, for example, he treats accidentality as an element, an ingredient or, as he literally puts it, a "component" of scientific discovery. He says that neither Ørsted's nor Röntgen's nor Becquerel's nor Fleming's discoveries "were really accidental, even though they had accidental components". Now, how is it possible not to be accidental and yet have accidental components? In fact, as we know, these discoveries were accidental in the sole sense of being unpredictable, but they were not accidental at all insofar as a prepared mind was able to recognize an event which, however anticipated in the mind, was itself wholly determined in the causal chains that existed independently of the subjective will of the scientist.

But the main difficulty Popper runs into, due to the above-mentioned untraced distinctions, is even more serious and repeats in essence the untenability of his distinction between psychology and research logic. According to Popper, the "accidental component" sometimes comes to the aid of other components, that is, the expectations generated by previously given hypotheses (the preparation Pasteur spoke of), but how this can happen again and again in the course of scientific research remains ultimately something quite inexplicable. It is of course true that serendipitous discoveries necessarily presuppose hypothetical or theoretical antecedent assumptions that prepare or open the minds of researchers, but one does not really dispel the paradox unless one provides a properly philosophical explanation of this

happy cooperation and correspondence between hypothetical anticipation and empirical discovery. How is it possible for the researcher to have formed in his or her mind precisely those theoretical assumptions or expectations that will later find a correspondence—accidental and therefore improbable by its very nature—in reality? Until this (or other similar and interrelated) questions are satisfactorily answered, it will not be possible to avoid a certain eclecticism, which rightly requires the combination of chance and method, but is unable to clarify the conditions of its possibility.

It is therefore by no means a coincidence, but the consequence of a fundamental distinction that has been overlooked, that for Popper serendipity can be no more than the simple eclectic sum, combination or juxtaposition of "planned insight coupled with unplanned events", to use Fine & Deegan's general definition of serendipity (cf. 1996, p. 445). In reality, as we have tried to clarify, every discovery originates from accidental (because not understood and therefore a fortiori unplanned) events that only thanks to the fundamental capacity of the human mind to assume anything real as hypothetical, become in the last a part of a "planned insight", i.e., a particular hypothesis that can represent a law-like concatenation of real events independent of our subjective will.

6 On the distinction between serendipitous and non-serendipitous discoveries

A consequence of what we have said is that, strictly speaking, every discovery is characterized by a certain degree of serendipity. From this point of view, the difference between discoveries that are serendipitous and those that are not can only be one of degree. This is in no way to deny that the historian or sociologist or psychologist may deem it appropriate to establish a certain boundary between cases of discovery in which the characteristics of serendipity are particularly marked. But however much one wants to insist on this difference in degree, one should not turn it into a qualitative difference.

This was clear to Merton. He rightly tried to better circumscribe the concept of serendipitous discovery, writing that what he called the "serendipity pattern" refers to "the fairly common experience of observing an unanticipated, anomalous and strategic datum which becomes the occasion for developing a new theory or for extending an existing theory." (Merton 1949, p. 98; but see also the more detailed interpretation of these terms on pp. 98–99.)

Some have sought also qualitative criteria. One of the most interesting attempts that seems to me to move at least to some extent in this direction is that of Arfini et al. 2020. According to the authors of this essay, serendipity phenomena occur not when a discovery was "wildly" unexpected, but when

it was "reasonably" unexpected. For example, the invention of the post-it note, which is clearly a kind of serendipitous discovery, took place because

> the chemists and engineers involved were glue-experts, and were able to recognize it. It made sense to them, it did fit the knowledge they had and the projections about their ignorance, so they were able to understand it. Had they stumbled upon something radically different, such as something with no gluing power but an amazing strawberry smell, they would have probably shrugged and thrown the batch away. It would have been something so wildly unexpected that it would have been uselessly bewildering. (Arfini et al 2020, p. 943)

The question now arises whether the distinction between a "wildly" unexpected discovery and a "reasonably" one is to be understood as a distinction of degree or of principle. In the former case we would be in the presence of an interesting characteristic, which in many contexts can be usefully added to those already specified by Merton.

If, on the other hand, the distinction were understood as a kind distinction, the criterion on the basis of which it is drawn would have to be rejected. In fact, because of the context in which the distinction in question is placed and on the basis of the example that illustrates it, it seems to be proposed as a principled distinction between serendipitous discoveries and discoveries without scientific relevance. Now, it is true that, in the sense we have called reflexive (or transcendental), the distinction marked by the terms "reasonably" and "wildly" would be qualitative, but as such it distinguishes true scientific discoveries from *entirely* accidental events or *entirely* irrelevant hypotheses. From this point of view, strictly speaking, there can be no accidental discoveries without scientific significance, but only mere events to which, at a certain stage of scientific research or human culture, we have not yet been able to attribute any cognitive significance.

It does not help much to resort to the distinction, proposed by Hendricks and Faye 1999, of two different types of abduction: "paradigmatic" and "trans-paradigmatic". Although useful for the specific purposes of particular historical-empirical research, even this distinction remains, strictly speaking, only a difference of degree and not, as the Arfini et al 2020 seem inclined to assume, a difference of principle. According to these authors, "paradigmatic" abduction is connected to discoveries that play the role of "game-changers" in scientific progress and therefore are genuine cases of serendipity (cf. Arfini et al. 2020, p. 946).

It is clear that the plausibility of the distinction between "paradigmatic" and "transparadigmatic" abduction is closely related to Kuhn's distinction between normal and revolutionary science. But while it is true that the distinction between evolutionary and revolutionary stages of scientific change may play an important role in the history of science (perhaps justified by the

particular purposes it serves from time to time), it cannot be interpreted as a qualitative difference, especially in the case we are discussing: neither from extraordinary science nor from 'normal' science can the note of creativity, novelty, unpredictability be completely expunged.

If the distinction between serendipitous and non-serendipitous discoveries is to remain a distinction of degree, in fact characterizing only the most serendipitous discoveries from those that are less so, it is good to reiterate one last time that the principled distinction that should not be overlooked is that between what is discovery for us and what is merely an actual event, since this distinction expresses the irreducible autonomy of human reason. From this point of view, however, all discoveries are serendipitous, both because they are all the result of human reason and because they are all marked by some degree of accidentality. For this reason, even the solution of a "puzzle" in Kuhn's sense is not guaranteed. It too may be unexpected at some point (for example, if so many good researchers in the field in the past have failed to find a solution) and requires a certain amount of creativity.[7]

7 Conclusion

In the context of the discussion on serendipity, the "paradox of control" emerged: on the one hand, serendipitous discoveries are accidental and unpredictable, but, on the other hand, they can be prepared, fostered and learned. The paradox, already anticipated by Heraclitus and Plato as a paradox related to obtaining new knowledge, brings to light the need to reconcile two essential elements of scientific discovery: unpredictability and genetic-methodological reconstructability. To resolve this paradox, I questioned both Popper's acceptance of the distinction between the psychology and the logic of knowledge and his later rejection of it as part of the relativistic-sociological turn.

This led to a distinction between two senses—one reflexive, the other genetic-methodical—of the psychology/logic (or discovery/justification) dichotomy. This distinction makes it possible to resolve the paradoxicality of serendipity (and scientific discovery in general) by clarifying in what precise sense both lucky initial chance and unpredictable human discovery are reconcilable with the principle of intersubjective testability of all scientific knowledge. A critical analysis of Popper's considerations of accidental discoveries in science both clarified the solution proposed here of the paradox of control and helped to capture the eclectic nature of Popper's position.

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[7] I developed this objection in Buzzoni 1986, pp. 32–51. Toulmin (1972, p. 106–107) was among the first to stress the need to understand the distinction between normal and revolutionary science as one of degree.

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References

Arfini S., Bertolotti T., Magnani L. 2020. The Antinomies of Serendipity How to Cognitively Frame Serendipity for Scientific Discoveries. Topoi 39, 939–948.

Bloor D. 1991. Knowledge and social imagery. 2nd ed, Routledge and Kegan Paul, London

Busch C. 2022. Towards a Theory of Serendipity: A Systematic Review and Conceptualization. Journal of Management Studies, 1–50 (doi:10.1111/joms.12890).

Buzzoni M. 1982. Conoscenza e realtà in K. R. Popper. Angeli, Milan.

Buzzoni M. 1986. Semantica, ontologia ed ermeneutica della conoscenza scientifica. Saggio su T.S. Kuhn. Angeli, Milan.

Buzzoni M. 2008. Thought Experiment in the Natural Sciences. Würzburg, Königshausen+Neumann.

Buzzoni M. 2015 The Practice Turn in Philosophy of Science: The Discovery/Justification Distinction, and the Social Dimension of Scientific Objectivity, pp. 81–111. In E. Agazzi and G. Heinzmann (eds.), The practical Turn in Philosophy of Science, Angeli, Milano.

Campbell D.T. 1960. Blind Variation and Selective Survival as a General Strategy in Knowledge Processes. In: M. C. Yovits and S. Cameron (eds.), Self-organizing Systems, 205–231. Pergamon Press, New York.

Case D. 2007. Looking for Information, 2nd ed., Academic Press, London.

Catellin S. 2014. Sérendipité. Du conte au concept. Seuil, Paris

Copeland S. 2019. On serendipity in science: Discovery at the intersection of chance and wisdom. Synthese, 196(6), 2385–2406.

Copeland S 2022. Metis and the Art of Serendipity. In Ross W. and Copeland S. (eds) 2022. The Art of Serendipity, pp. 41–73. Macmillan, Palgrave.

Copeland S. 2023. Serendipity and the History of the Philosophy of Science. In: S. Copeland, W Ross & M. Sandet (eds), Serendipity Science, pp. 101–123. Cham.Springer.

De Rond M. 2014. The structure of serendipity. Culture and Organization, 20(5), 342–358.

Feyerabend P. K. 1970. Against method: Outline of an Anarchistic Theory of Knowledge. In: Radner M, Winokur S (eds), Analyses of Theories and Methods of Physics and Psychology, Minnesota Studies in the Philosophy of Science, IV. University of Minnesota Press, Minneapolis, pp. 17–130.

Fine G. A., and Deegan J.G. 1996. Three principles of Serendip: Insight, chance, and discovery in qualitative research. International Journal of Qualitative Studies in Education, 9(4), pp. 434–447.

Fink, T. M. A., Reeves, M., Palma, R., & Farr, R. S. (2017). Serendipity and strategy in rapid innovation. Nature communications, 8(1), 1–9.

Foster, A. E., & Ellis, D. 2014. Serendipity and its study. Journal of Documentation, 70(6), 1015–1038 (doi: 10.1108/JD-03-2014-0053).

Gherardi S. 2006. Organizational Knowledge: The Texture of Workplace Learning, Blackwell Publishing, Oxford.

Glăveanu Vlad P. 2022. What's 'Inside' the Prepared Mind? Not Things, but Relations. In Ross W. and Copeland S. (eds) 2022. The Art of Serendipity, pp. 23–39. Macmillan, Palgrave.

Hendricks FV, Faye J 1999. Abducting explanation. In: Magnani L., Nersessian N. J., Thagard P. (eds) Model-based reasoning in scientific discovery. Kluwer Academic/Plenum Publishers, New York, pp. 271–294.

Hoyningen-Huene P. 1987. Context of discovery and context of justification. Studies in History and Philosophy of Science Part A, 18(4), pp. 501–515.

Kirk G. S., Raven J. E., Schofield M. 1983. The Presocratic Philosophers. A Critical History with a Selection of Texts, 2nd ed, Cambridge University Press, Cambridge/New York/New Rochelle

Kotkov D., Medlar A., and Glowacka D. 2023. Rethinking Serendipity in Recommender Systems. In ACM SIGIR Conference on Human Information Interaction and Retrieval (CHEER '23), March 19–23,

2023, Austin, TX USA. ACM, New York, NY, USA, 5 pages (doi: 10.1145/3576840.3578310).

Kuhn T.S 1962. The Structure of Scientific Revolutions, University of Chicago Press, Chicago (quotations are from the second edition, 1970)

MacDonald S 1998. Information for Innovation, Oxford University Press, Oxford.

Mann H. 1754. Letter from Mann, Friday 8 March 1754. Quotations are from W. S. Lewis, W. H. Smith and G. L. Lam (eds.), Horace Walpole's Correspondence with Sir Horace Mann, Vol. 4, pp. 414–416. Yale University Press, London 1960.

Marcovich, M. 1967. Heraclitus. The Greek text with a short commentary. Los Andes University Press, Merida.

Mason, Andrew J. 2014. Heraclitus' Usage of ὅστις in Fragments DK B 5 and B 27. Phronimon 15(2), pp. 55–68.

McBirnie A. 2008. Seeking serendipity: the paradox of control. Aslib Proceedings: New Information Perspectives, 60(6), pp. 600–618.

Merton, R. K. 1945. Sociological Theory. American Journal of Sociology, 50, pp. 462–473.

Merton, R. K. 1948. The Bearing of Empirical Research upon the Development of Social Theory. American Sociological Review, 13, No. 5, pp. 505–515.

Merton, R. K. 1949. Social Theory and Social Structure. Toward the Codification of Theory and Research. The Free Press of Glencoe, Illinois.

Merton, R. K. and Barber, E. 2004. The Travels and Adventures of Serendipity. Princeton University Press, Princeton.

Nickles T. 2009. The Strange Story of Scientific Method. In: J. Meheus and T. Nickles (eds.), Models of Discovery and Creativity, pp. 167–207. Springer, Dordrecht Heidelberg London New York.

Pasteur L. 1854. Discours à l'occasion de l'installation solennelle de la Faculté des lettres de Douai et de la Faculté des sciences de Lille. Impr. A. d'Aubers, Douai. Repr. and quoted from: Oeuvres complètes réunies par Pasteur Vallery-Radot. Tome VII: Mélanges scientifiques et littéraires, pp. 129–132. Masson et Cie Éditeurs, Paris. 1939.

Plato 1997. Complete Works, Edited, with Introduction and Notes, by John M. Cooper, Hackett Publishing Company, Indianapolis/Cambridge.

Poincaré H. 1906. La valeur de la science, Flammarion, Paris. Engl. Transl. by G. B. Halsted, The Foundations of Science, Science Press, New York. 1913, pp. 201–358.

Poincaré H. 1908. L'invention mathématique, Bulletin de L'institut Général Psychologique, 1908, Vol. 8, 175–187. Engl. Transl. by G. B. Halsted, Mathematical Creation. The Monist, 1910, Vol. 20 (3), pp. 321–335.

Popper K. R. 1935. Logik der Forschung, Springer, Wien. Engl. Transl. From The Logic of Scientific Discovery. Routledge, London, 2002.

Popper K. R. 1957. The Poverty of Historicism. The Beacon Press, London.

Popper K. R. 1969. Conjectures & Refutations, Routledge & Kegan Paul, London, 3rd revised edition.

Quy Khuc 2022. How do we perceive serendipity? In: QH Vuong (ed), A New Theory of Serendipity: Nature, Emergence and Mechanism, pp. 13–40. De Gruyter, Berlin.

Schickore J. and Steinle F., eds. (2006) Revisiting discovery and justification: historical and philosophical perspectives on the context distinction. Springer, Dordrecht

Sun, X., Sharples, S., & Makri, S. (2011). A user-centred mobile diary study approach to understanding serendipity in information research. Information Research, 16(3).

Thagard P. 1998a. Ulcers and bacteria I: discovery and acceptance. Stud Hist Philos Sci C 29(1):107–136.

Thagard P. 1998b. Ulcers and bacteria II: Instruments, experiments, and social interactions. Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences, 29(2), 317–342.

Toulmin S. 1972. Human Understanding. The Collective Use and Evolution of Concepts, vol. I, Princeton University Press, Princeton (N.J.).

Van Andel P. 1994. Anatomy of the unsought finding. Serendipity: Origin, history, domains, traditions, appearances, patterns and programmability. Br J Philos Sci 45(2): 631–648.

Wallas G. 1926. The Art of Thought. Cape, London.

Waller J. 2002. Fabulous Science: Fact and Fiction in the History of Scientific Discovery. Oxford University Press, Oxford.

Walpole H. 1754. Letter to Sir Horace Mann, Monday 28 January 1754. Quotations are from W. S. Lewis, W. H. Smith and G. L. Lam (eds.), Horace Walpole's Correspondence with Sir Horace Mann, Vol. 4, Yale University Press, London, 1960, pp. 407–411.