Serendipity: an argument for scientific freedom?

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Abstract

The unpredictability of the development and results of a research program is often invoked in favor of a free, desinterested science that would be led mainly by scientific curiosity, in contrast with a use-inspired science led by definite practical expectations. This paper will challenge a crucial but underexamined assumption in this line of defense of scientific freedom, namely that a free science is the best system of science to generate unexpected results. We will propose conditions favoring the occurrence of unexpected facts in the course of a scientific investigation and then establish that use-inspired science actually scores better in this area.

1. Introduction

"I didn't start my research thinking that I will increase the storage capacity of hard drives. The final landscape is never visible from the starting point." This statement made by the physicist Albert Fert (2007), winner of the 2007 Noble Prize for his work on the giant magnetoresistance effect, expresses a very common belief, especially among scientists, about the unpredictable nature of the development and results of a research program. Such retrospective observations feed a type of "unpredictability argument" often invoked in favor of a pure, disinterested science led by scientific curiosity, in contrast with a use-inspired or applied science led by practical considerations. Polanyi gave a somewhat lyrical form of this kind of unpredictability argument in his classical essay "The Republic of Science" (1962). Science, says Polanyi (1962, 62), "can advance only by unpredictable steps, pursuing problems of its own, and the practical benefits of these advances will be incidental and hence doubly unpredictable. … Any attempt at guiding research towards a purpose other than its own is an attempt to deflect it from the advancement of science… You can kill or mutilate the advance of science, but you cannot shape it." In Polanyi's view, claims about the unpredictable nature of scientific development go hand in hand with a plea for an *internal* definition of research priorities: a problem should be considered important in light of considerations internal to a field of scientific inquiry and not (at least not primarily) in light of external considerations, such as practical utility. The orientation of the inquiry by practical objectives is then deemed epistemically counter-productive and vain: one should not attempt to predict the unpredictable.

In response to this line of defense of free science, some authors emphasize the epistemic fecundity of use-inspired science (Stokes 1997, Wilholt 2006, Carrier 2004) showing that the presence of practical objectives does not run counter to the building of fundamental knowledge: more fundamental knowledge may be needed to achieve some particular practical ends. Industry research on the giant magnetoresistance effect in the 1990s is a telling example of research undertaken under considerable pressure to produce applicable results but which nevertheless produced, along the way, new fundamental knowledge (Wilholt 2006).

Our aim in this paper is to develop another line of defense of the epistemic fecundity of applied science, by challenging a crucial but often implicit assumption in the traditional defense of scientific freedom based on scientific unpredictability (such as Polanyi's or Fert's), namely the assumption that a free science is the best system of science to generate unexpected facts. But what are actually the conditions favoring the emergence of novelty in the course of a scientific investigation? This important issue has not received much epistemological attention.[1] We will fill this gap by first distinguishing two kinds of unpredictability arguments often mixed when debating on scientific freedom, to wit, unpredictability as unforeseen practical applications and unpredictability as *serendipity* (cases, as we will explain in more details, where unexpected facts open up new lines of inquiry). Focusing on the latter, we will propose two conditions that favor the occurrence of unexpected facts in the course of a scientific investigation. In light of these two criteria we will then compare pure, disinterested science and applied science as regards their capacity to generate novelty.

2.Two types of unpredictability arguments

Appeals to the unpredictability of scientific results actually refer to various kinds of situations, which need to be clearly distinguished. First, the notion of unpredictability of scientific results can designate unforeseen practical applications of fundamental knowledge. Second, it can refer to a serendipitous dynamics of scientific progress: a line of research may sometimes lead to a totally unexpected, surprising result, which opens a new direction of inquiry. These two kinds of unpredictability give rise to *distinct* arguments in favor of scientific freedom, unfortunately often mixed in discussions about the relative merits of pure science and application oriented science.

2.1 Unpredictability as unforeseen practical applications

When unpredictability refers to unexpected applications, the argument is the following: freedom of research should be preserved since a free, disinterested science is needed to generate a reservoir of fundamental knowledge, which then can be used to develop

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[1] Wilholt and Glimell (2011, 353) do touch upon this issue when discussing the link made by proponents of the autonomy of science between freedom of research and diversity of approaches favoring the epistemic productivity of science. But they just note that it is a strong assumption and do no further discuss its validity.

applications. This argument was typically developed by Vannevar Bush who appealed to the now classically called linear model of innovation:

> “Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown" (1945, 20).

The development of the H-bomb in the frame of the Manhattan project is a paradigmatic case, also invoked by Bush: “basic discoveries of European scientists" (1945, 20) about the structure of the matter is what made possible the military application. Another frequently cited example of unpredictable application is the invention of the laser, a widely-used technological device nowadays, made possible by pure theoretical developments in quantum physics during the first half of the XXth century.

We will not in this paper discuss further this first version of the unpredictability argument. Let us just mention that its underlying linear model of innovation linking pure science and practical applications has already been challenged on several grounds by various authors (e.g. Brooks, 1994; Leydesdorff, 1997; Edgerton, 2004; Rosenberg, 1992). We rather want to focus on the second (and also widespread) type of unpredictability arguments, whose validity has been much less scrutinized.

2.2 Unpredictability as serendipity

This second type of argument appeals to unpredictability in the sense of *serendipity*: an unexpected observation or result opens up a new line of research leading to a fundamental discovery. A very well known historical episode illustrating such a serendipitous scientific dynamics is the invention of the first antibiotic by Flemings, after he had accidentally observed the effect of a fungi (Penicilium) on bacteria colonies (Flemings, 1929). Also often cited is the discovery of radioactivity by Henri Becquerel (1896): when working with a crystal containing uranium, Becquerel noted that the crystal had fogged a photographic plate that he had inadvertently left next to the mineral. This observation led to the hypothesis that uranium emitted its own radiations. Another, perhaps less cited instance of serendipitous scientific dynamics is the discovery of the chemotherapeutic cisplatine molecule by scientists initially working on the effects of an electric field on bacteria growth (Rosenberg *et al.*,1967). They observed that cell division was inhibited because of the unexpected formation of a chemical compound with the Platinum atoms contained in the electrode. This chemical compound, which they named cisplatine, was then successfully tested as an anti-proliferative agent against tumoral cells.

When unpredictability refers to such serendipitous discoveries, freedom of research is defended on the grounds that scientists should be able to freely change the direction of their research or open up new lines of inquiry, in order to be able to follow up on unexpected results, thereby generating new knowledge (which in turn will possibly lead to new applications). But to properly work as an argument favoring free, disinterested research over applied research, this “serendipity argument” actually presupposes that the occurrence of surprising facts is more likely to happen in the first system of science than in the second. For increasing the production of new knowledge (and possibly new applications) does not only depend on being able to freely follow up on unexpected facts, it also (obviously) depends on whether occurrences of unexpected facts are favored, to start with. Two types of considerations are thus mixed in the serendipity argument: considerations on the occurrence of unexpected facts and considerations on the (institutional, material) possibility to follow up on them.

We will not for the moment discuss the second type of considerations and focus on the first, which has been largely neglected in the literature on scientific freedom, namely the conditions that favor the occurrence of surprising facts. Our central issue is thus the following: is a use-inspired science less likely to generate unexpected results than a free science mainly fuelled by curiosity? After having clarified the notion of *unexpected* result, we will propose two criteria that, we will argue, favor the occurrence of such results and in light of which free science and applied science can be compared.

3. Conditions of emergence of unexpected facts

By "unexpected facts" occurring in the course of an inquiry, we simply mean here results (observations, outcomes of an experiment, etc.) that cannot be accounted for within the theoretical or, more largely, the epistemic framework in which the empirical inquiry has been conceived and conducted. This kind of "exteriority" is what leads scientists to move away from the initial explanatory framework and open up new lines of inquiry in search of an alternative one that could accommodate the unexpected results.

3.1 Isolation and purification of phenomena

It is now a well-known feature of contemporary experimental sciences that many of their objects under study are "created" in the laboratory rather than existing "as such" in the real world. When drawing our attention to this epistemologically important feature, Hacking (e.g. 1983, chap. 13) specified that we should not read this notion of "creation" of phenomena as if *we* were *making* the phenomenon, suggesting instead that a phenomenon is "created" in the laboratory to the extent that it does not exist outside of certain kinds of apparatus. This is typically the case for a phenomenon like the Hall effect: it did not exist "until, with great ingenuity, [Hall] had discovered how to *isolate*, *purify* it, create it in the laboratory" (Hacking

1983, 226, *our italics*). In other words, Hall created in 1879 the material arrangement - a current passing through a conductor, at right angles to a magnetic field –, for the effect to occur and "if anywhere in nature there [were] this arrangement, *with no intervening causes,* then the Hall effect [would] occur" (1983, 226, *our italics)*. Isolation, purification, control of intervening causes (i.e. control of physical parameters) are noticeable features of an experimental protocol that have a straightforward consequence directly relevant for our philosophical interrogation on serendipity: they tend to limit the number of causal pathways which can influence the response of the object or phenomenon under study experimentally. Unknown causal pathways existing in the real world are thus inoperant (or less operant) in laboratory conditions, thereby limiting the occurrence of unexpected results. Hence our first criterion to evaluate whether a certain system of science favors surprising results: the more the phenomena under study in that system are isolated, purified in highly regimented experimental conditions, the less likely the occurrence of unexpected results is.

Moreover, isolation, purification of phenomena often go hand in hand with another noticeable feature of laboratory sciences, described by Hacking as follows: "as a laboratory science matures, it develops a body of types of theory and types of apparatus and types of analysis that are mutually adjusted to each other" (1992, 30). In particular, a given theoretical framework determines the type of questions that can be probed experimentally, guides the design of apparatus and defines the type of data produced. Consequently, "data uninterpretable by theories are not generated" (Hacking 1992, 55). This process of mutual constraints is well illustrated for instance by recent experimental inquiries in particle physics, such as the quest for the Higgs Boson. Its existence was postulated in the frame of the Standard Model of theoretical physics (Higgs, 1964) and complex experimental apparatus have been developed with the explicit goal of "discovering" it (LEP, 2003). The "discovery" occurred in 2012 (ATLAS, 2012) but the high degree of tailoring of the apparatus to the theory postulating the particle can be considered as imposing some kind of a priori structure on the phenomenon, so that particles such as the Higgs boson are not so much "discovered" than "manufactured" (Falkenburg, 2007, 53). In any case, the "discovery" of the Higgs boson was hardly a surprise and illustrates Hacking's more general contention about experimental inquiries typical of contemporary laboratory sciences as opposed to real-world experiments: "[their] results are more often *expected* than *surprising*" (1992, 37, *our italics*).

3.2 Theoretical unifying ambition

Another relevant characteristic of an experimental inquiry is the degree of generality of its theoretical framework. Scientists working within a theoretical framework with a large unifying scope will be reluctant to "leave" it and search for an alternative one when facing an unexpected result, and for good epistemological reasons: there is (obviously) a high epistemic cost of abandoning a theoretical framework that provides explanations for a large set of phenomena. The right move is rather to try to accommodate the surprising result by adopting, if necessary, *ad hoc* hypothesis or tinkering with some ingredients of the existing theoretical framework, so that the result looses its "exteriority" and ends up being integrated. And because of this well-known "plasticity" and integrative power of well-established theoretical frameworks with a large unifying scope[2], when a (at first sight) surprising result occurs, it rarely leads to the opening up of a new line of inquiry in search of an alternative explanatory framework, but rather gets integrated within the existing one, thereby losing its unexpectedness.

There is another reason why a high degree of theoretical generality does not favor the occurrence of unexpected results, which is linked to our previous remarks on the process of

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[2] Classical references on these ideas of plasticity or integrative power are of course Kuhn's description (1962) of scientists being busy working on resolving anomalies in normal science and Lakatos' concept of "protective belt" of a research program (1978).

mutual adjustment between theoretical ingredients, apparatus and data. By constraining the type of experimental procedures developed and the type of data generated, a theoretical framework with a large unifying scope tends to *homogenize* the experimental works conducted to probe the various phenomena that it accounts for. And since a diversity of experimental approaches increases the possible sources of emergence of surprising facts, we can conclude that by reducing this diversity, theoretical generality makes the occurrence of unexpected facts less likely to happen.

The case of the etiology of cancer provides interesting illustrations of these two unexpectedness-diminishing effects of theoretical generality. The classical theory of cancer, the Somatic Mutations Theory (SMT), has been challenged for fifteen years or so by a new theoretical approach, the Tissue Organization Field Theory (TOFT) (Sonnenschein and Soto, 2000). First developed in the 1970's, the SMT rapidly became the dominant research theoretical framework on carcinogenesis (Mukherjee, 2010). This hegemony led to a high degree of homogenization of the experimental inquiries: the experimental procedures were all dedicated to the very standardized search for genetic mutations, in the context of molecular biology. Moreover, many, if not all surprising observations were made compatible with SMT by using *ad hoc* hypothesis (Soto, 2011). For instance, it was observed that various types of cancer were exhibiting large-scale disorganization of the genome. This observation was unexpected to the extent that it could not fit with SMT's fundamental postulate of punctual mutations. To integrate it in the frame of SMT, the existence of an original genetic instability of the cancer cells was then postulated (Rajagopalan, 2003).

4 Use-inspired science, pure science, and unexpected facts

In light of the criteria that we proposed above, how does pure, disinterested science score compared to applied science when it comes to favoring the occurrence of unexpected facts? A helpful starting point is provided by Martin Carrier’s insightful characterization of applied science:

> “Three methodological features can be observed whose combined or marked appearance tends to be characteristic of applied science: local models rather than unified theories, contextualized causal relations rather than causal mechanisms, real-experiments rather than laboratory experiment conducted for answering theoretical questions" (2004, 4).

4.1 Local models

Let us start with the contrast between local models and unified theories. Whereas pure science often aims at providing comprehensive and unifying theoretical frameworks (think of the Standard Model in particle physics or the Big Bang model in cosmology), use-inspired research is characterized by the coexistence of numerous local models, each determining the development of specific experimental procedures. An extreme case of this locality are for instance the design-rules used in the industry, which are built as laws guiding action (Wilholt, 2006). They are experimentally confirmed rules providing relations among different relevant parameters to manufacture industrial products. These rules are extremely specific: they apply to a very few number of situations and each of them determines a singular experimental practice. The use of local models is also widespread in the biomedical sciences, a typically use-inspired field of research. We will again draw on oncology to illustrate our point. Consider for instance the case of the development of radiotherapy protocols in the first half of the XXth century. The aim was to intervene on cancer to cure it, without any general model describing the mechanism of carcinogenesis. This program promoted the development of a variety of exploratory approaches using X-rays against cancer (Pinell, 1992). As there were no standardized protocols, many experimental procedures were tested, changing the density of X-rays received, the distance of emission, the frequency of the radiotherapy sessions. In order to improve the efficiency of the therapeutic methods, scientists tried to build various local models describing the action of X-rays on cancer, corresponding to the variety of experimental procedures implemented. Grubbe (1949) formulated a model based on the inflammatory reaction to explain the effects of radiotherapy on cancer: the inflammation of the surrounding tissue beyond the effects of X-rays is responsible for the decrease of tumoral mass. This model is applicable to his specific use of X-rays: he applied very high doses, necessary to generate an inflammatory response. In parallel, Tribondeau and Bergonié, using more moderate doses, developed a model based on the proliferation of the cells in tumoral context, which led to the "Bergonié law": X-rays have a higher impact on proliferating cells (Tribondeau, 1959).

What lessons can be drawn from this first contrast between local models and unified theories? The answer is rather straightforward, given the link spelled out in the previous section between the level of generality of theoretical models and the occurrence of unexpected facts (our second criterion): by promoting the use of a diversity of local models and heterogeneous experimental protocols, applied science favors the occurrence of unexpected facts, whereas the penchant of pure science for comprehensive unifying theoretical frameworks, hence homogenized experimental protocols, does not.

4.2 Causal incompleteness

Let us compare now pure science and applied science in light of our first criterion based on the degree of isolation and purification of the phenomena under study. A directly relevant feature of applied science is the use of what Carrier calls “contextualized causal relations” rather than full causal chains. Use-inspired science typically aims at directly intervening on a process or phenomenon often disposing only of a partial knowledge of the causal chains involved and without being able to isolate it from various causal influences exerted by the rest of the physical world. A direct consequence of this feature of applied science is the low degree of control of its experimental protocols. By contrast, since pure science aims primarily at answering fundamental theoretical questions, it designs highly regimented experimental procedures that isolate and purify phenomena in order to be able to get empirical answers about the specific fundamental processes questioned in the theoretical investigation[3]. Moreover, building highly regimented experimental procedures requires knowledge of full causal chains in order to be able to better control the response of the system under study. The outcome of the application of our criterion is then again straightforward: compared with pure science, applied science favors the occurrence of unexpected facts to the extent that its experimental procedures are less controlled and based only on partial knowledge of the causal influences exerted on the phenomenon under study.

The etiology of cancer provides again interesting illustrations of our claim. Indeed, many current cancer therapies built in the frame of use-inspired research are based on contextualized causal relations. Typically, if a cellular agent is found to be massively expressed in cancer cells, drugs are designed to inhibit it, even if the whole causal chain determining its action is not known. For instance, a large amount of proteins promoting angiogenesis (the growth of blood vessels), notably VEGF (Vascular Endothelial Growth Factor), was found in tumoral cells, leading to the design of anti-VEGF molecules (Sitohy,

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[3] Carrier sums up this contrast as follows: “Empirical tests often proceed better by focusing on the pure cases, the idealized ones, because such cases typically yield a more direct access to the processes considered fundamental by the theory at hand. But applied science is denied the privilege of epistemic research to select its problems according to their tractability (...). Practical challenges typically involve a more intricate intertwinement of factors and are thus harder to put under control". (2004a, 4) In the life sciences, this focus on “pure cases” means using “model organisms” or a limited number of well spread cell lines (e.g. the HeLa cells or the Saccharomyces Cerevisiae yeast) to elucidate fundamental biological mechanisms. And the use of such standardized objects tends to homogenize the experimental protocols.

2012). These molecules are used without considering the complete causal chain in which the VEGF is embedded. Only their known action on angiogenesis is considered. The clinical tests have led to unexpected observations: the use of an anti-VEGF molecule (Avastin) can stimulate tumor growth (Lieu *et al.*, 2013)[4]. This example shows that the use of contextualized causal relations promotes the appearance of surprising facts by allowing unknown mechanisms to intervene in the experimental procedure.

5. Concluding discussion

Our previous analysis has established that several features of pure, disinterested science make it less hospitable than use-inspired science to the occurrence of unexpected facts. For all that, it does not follow that proponents of freedom of science cannot appeal anymore to unpredictability in the sense of serendipity to make their case. For the issue of which conditions favor the occurrence of unexpected facts is only half of the story. The other half is the possibility to actually follow up on these occurrences and open new lines of inquiry. And this other half raises different issues. What are the institutional, social structures of science that make it easier for scientists to re-orient their research when needed? To what extent an initial orientation of a scientific investigation by “external” practical needs is less compatible with the opening of new lines of inquiry than an initial orientation by epistemic considerations internal to the dynamics of a scientific field? When appealing to the serendipity argument,

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[4] Interestingly, this observation led to new use-inspired research programs, aiming at identifing the molecular causal pathways giving rise to this tumoral resistance phenomenon. It has notably strongly oriented the research toward the precise understanding of the VEGF pathways (Moens, 2014). For instance, the study of the mechanisms of expression in cancer cells of various kinds of VEGF agents is becoming an important program of research (Li, 2014) and these works allow to build new fundamental knowledge about the action of the VEGF proteins.

proponents of free, disinterested science not only presuppose that it is the best system of science to generate unexpected facts to start with – a contention that we have challenged in this paper – but also that it actually gives more freedom to scientists to follow up on unexpected results. In other words, the issue of scientists' given possibility to change the direction of their research when needed is somewhat mixed, confused with the normative issue of what the aims of science should be (in short, increase knowledge following considerations internal to science *vs.* answer external practical needs). But it seems to us that the two issues should be kept separate. After all, one can very well conceive a system of science whose aims are primarily to answer society needs but which nevertheless leaves scientists free to choose the lines of inquiry that seem *to them* the most promising ways of fulfilling these needs (which includes changing research directions if needed). Otherwise put, one can very well conceive a use-inspired science which is not a *programmed* science in which scientists are asked to plan every step of their inquiry in order to achieve a given aim. And note that a pure, disinterested science may be as much programmed as a use-inspired science: the fact that scientists are left free to choose the aims of their research does not protect them from having to plan every step to reach these aims. In any case, our purport in this paper was not to attack pure, disinterested science. There are, no doubt, many good reasons to defend it, but the widespread, traditional one grounded on the unpredictability of scientific inquiry is certainly not the most epistemologically cogent and solid one.

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