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Interdisciplinary Research Boosted by Serendipity

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Interdisciplinary research can be defined as the practice of discovering new objects of knowledge beyond disciplinary borders. It often operates through the cross-fertilization and hybridization of concepts, theoretical frameworks, and methodological tools to enable the description, analysis, and understanding of the complexity of objects of study that cannot be reduced to the strict limits imposed by any one discipline. The aim of this article is to take stock of the theoretical and methodological issues involved in the interdisciplinary research process from the perspective of serendipity, which is a creative process of considerable value to science. The intent is to show that the decompartmentalization of disciplines, the ability to decenter and open one's mind to the unexpected are intrinsic to the work of researchers who position themselves between and beyond disciplines. Our contention is that, as a process of discovering with a completely open mind (*sine anticipatio mentis*) things that are not being searched for, serendipity is thus capable of playing a central role in interdisciplinarity, boosting the exchange of ideas and speeding up their circulation among researchers committed to exploiting the heuristic dimension of the unexpected.

INTERDISCIPLINARY RESEARCH BOOSTED BY SERENDIPITY

> Each discipline can be compared to a jar. Once we are in the jar, it takes genius to get ourselves out of it or to innovate: we feel that the jar's boundaries are natural. (Veyne, 1983, p. 127)[1]

The growing interest in interdisciplinarity has been fuelled by awareness among teachers-researchers[2] of the complexity of numerous research problems that cannot be tackled from the perspective of a single discipline and require the piecing together of fragment of knowledge. The need for interdisciplinarity has intensified because there is a high demand for it among social actors, citizens, politicians, and economists, who expect science to provide concrete and comprehensive answers to current challenges in a large number of areas, such as the environment, education, health, energy, urban planning, etc. (see Thompson Klein et al., 2001). It should also be stressed at the outset that not only is interdisciplinarity supported by the institutional discourses of academia and the world of politics, it has also become a focus of reflection and research in its own right. It has been extensively exploited in the scientific literature, which has considered it from various standpoints: epistemological, theoretical, methodological, and practical. A casual glance at the contents of recent publications that provide an overview of interdisciplinarity provides clear evidence

[1]All translations in the text are ours unless otherwise noted.

[2]The masculine gender is used in this text solely for reasons of stylistic economy and should not be construed as discriminatory.

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of the theoretical and practical advances made in this field: worthy of particular mention are the *Oxford Handbook of Interdisciplinarity* (Frodeman, Thompson Klein, & Mitcham, 2010), the *Handbook of Transdisciplinary Research* (Hirsch Hadorn et al., 2008) and also, focussing on the Swiss academic context, the bilingual *Le défi de l'Inter- et Transdisciplinarité. Concepts, méthodes et pratiques innovantes dans l'enseignement et la recherche* (Darbellay & Paulsen, 2008). The publication of handbooks and overviews of this kind is a reliable indicator that a legitimate field of study has become established and is officially sanctioned by a scientific community interested in the challenges of interdisciplinarity in teaching and research, with regard to theoretical framings, methodological tools, and case studies leading to examples of what, on the whole, counts as good practice.[3]

Although discussion of the dialogue between disciplines goes back a long way in the history of science, especially since the creation of the mediaeval universities, which, even then, were wavering between academic specialization and the need to build bridges between disciplines (Gusdorf, 1983), it is generally agreed that the problematic of interdisciplinarity as such emerged in the 1960s and 1970s (Thompson Klein, 1990). The important seminal contribution by the Organization for Economic Cooperation and Development on the place of interdisciplinarity in universities (Apostel, Berger, Briggs, & Michaud, 1972) already marked an important stage in the study of the challenges and of the forms of collaboration between disciplines in teaching and research. Berger (1972) envisaged interdisciplinary work as an interaction among two or more different disciplines:

> This interaction may range from simple communication of ideas to the mutual integration of organising *concepts, methodology, procedures, epistemology, terminology, data*, and organisation of research and education in a fairly large field. An interdisciplinary group consists of persons trained in different fields of knowledge (disciplines) with different concepts, methods, and data and terms organised into a common effort on a common problem with continuous intercommunication among the participants from the different disciplines. (p. 25)

With much foresight, the multiple dimensions of interdisciplinarity were identified, not only at the institutional level, at which universities are organized almost exclusively along disciplinary lines, but also at the conceptual, theoretical, and methodological levels, as well as in terms of the forms of cooperation between researchers. Within the narrower scope of this article, the specific concern is with the process of interdisciplinary research and we base our reflections on the analyses and statements made in the literature concerning the stages, mechanisms, and development of interdisciplinary work. More specifically still, the question of interdisciplinarity is revisited to consider the impetus it can be given by the creative phenomenon of serendipity. In other words, does the interdisciplinary research process, as it is presented—more or less consensually—in the literature, take account of the unexpected, which can suddenly appear at any time in research conducted outside the laboratory? And if serendipity is taken into account, to what extent is it likely to influence, or even reconfigure, the interdisciplinary research process; to boost it in the sense of the unexpected being capable of opening up unexpected avenues in scientific discovery at the borders of disciplines and beyond them? This is addressed in two complementary stages. Starting with a working definition of interdisciplinarity and its implementation in the research process, the properties of serendipity are then given as a process of discovery in a way that brings *interdisciplinarity* and *serendipity* together. The question concerns whether they are capable of mutually enriching each other.

INTERDISCIPLINARITY AS A PROCESS

Defining Interdisciplinarity

Critical reflection on interdisciplinarity is characterized by the use of terms that are markedly polysemous in nature: monodisciplinarity, polydisciplinarity, codisciplinarity, pluri- or multidisciplinarity, interdisciplinarity, transdisciplinarity, etc. The terms are legion and the prefixes that qualify or transform the root concept of *discipline* conjure up a shadowy semantic presence that is relatively complex. Nevertheless, the main works on interdisciplinarity are unanimous in defining different levels in the dialogue between disciplines, focussing on the degrees of decompartmentalization, interaction and integration between them. The key concepts that emerge are: (a) *pluri-* or *multidisciplinarity*, (b) *interdisciplinarity* and (c) *transdisciplinarity* (see Darbellay, 2005; Huutoniemi, Thompson Klein, Bruunc, & Hukkinena, 2010; Piaget, 1972; Thompson Klein, 1990).

The distinct but complementary stages in the dialogue between disciplines can be defined succinctly as follows:

> *Pluri-* or *multidisciplinarity* is aimed at studying a given object or solving a theoretical or practical problem by referring to two or more unconnected disciplinary viewpoints in succession, without any

[3]The study of the complexity of the interdisciplinary research process is the focus of our research project: "Analyzing Interdisciplinary Research: From Theory to Practice. Case studies in the Swiss University Context." The project is funded by the Swiss National Science Foundation (FNS/Specialist Committee for interdisciplinary research, Application: CR11I1_143816), 2013–2014.

real interaction occurring between them. This approach endorses, so to speak, the institutionalization and standardization of socially and historically entrenched teaching and research practices governed by compartmentalized scientific paradigms. It reflects the traditional institutional juxtaposition of a plurality of specialist communities, organized in as many faculties, departments, and laboratories that are relatively independent of one another.

Interdisciplinarity brings together two or more established disciplines so that they interact dynamically, the aim being to analyze and understand the complexity of a given object of study or solve a theoretical or practical problem. Interdisciplinarity, which goes further than simply juxtaposing disciplinary viewpoints, brings into play the collaboration and integration of specific disciplines in relation to a common object. The process of dialogue between the disciplines requires each participating researcher to deploy the analytical skills and tools of their own disciplines while, at the same time, opening their minds to the methods of the other disciplines: the complex, emerging knowledge object is thus coconstructed in and through the interdisciplinary research process, on the basis of existing competencies, while remaining irreducible to any single one of the disciplinary viewpoints involved. The collaborative approach and integration of the discipline-specific knowledge can take place at different levels of interaction: It can be a matter of scientific fields transferring or borrowing concepts, theories, or methods from one another, of hybridization or cross-over mechanisms between disciplines, or even the creation of new fields of research through the coupling of two or more disciplines. In all these scenarios involving interdisciplinary procedures, the organization of knowledge is based on interactions between a plurality of viewpoints and the issues and problems treated are located between(*inter*-) the disciplines and cannot be explored from a single disciplinary perspective in isolation.The term *transdisciplinarity* denotes a knowledge process that transcends (*trans*-) and crosses disciplinary boundaries, and entails a major reconfiguration of disciplinary divisions within an all-encompassing perspective (Nicolescu, 1996; Piaget, 1972). In a more pragmatic, participatory, and applied version, transdisciplinarity is also a research procedure that takes on board political, social, and economic actors, and ordinary citizens in a problem-solving (Clark, 2002) or issue-driven research (Robinson, 2008) perspective. Actors from outside the scientific domain are encouraged to actively participate in the coconstruction of knowledge and the resolution of social problems that extend beyond the boundaries of any one discipline (e.g., violence, poverty, climate change, pollution, and social and financial crises; see Gibbons et al., 1994; Hirsch Hadorn et al., 2008; Thompson Klein et al., 2001). It should also be noted that transdisciplinarity equally applies to the exploration of the complex relations that are woven between scientific cultures that have their origin in the technological sciences, life sciences, and natural sciences, on the one hand, and the humanities and social sciences on the other (see Darbellay, Cockell, Billotte, & Waldvogel, 2008).

From multi- to inter- and transdisciplinarity, there is a clear, reasonably coherent semantic and epistemological dynamic, which consists in tying these approaches to the anchor points offered by disciplines, while at the same time incorporating them into a network of relations that becomes progressively more dense and interactive. Interdisciplinarity, the concept on which we mainly focus in this article, thus assumes its full meaning within this dynamic: Although it is based on the juxtaposition of several disciplines, which is a feature of multidisciplinarity, it transcends this juxtaposition and represents a decisive stage in the gradual integration of the disciplines in a transdisciplinary perspective.

A Process of Integration Between Disciplines

Taking as our starting point interdisciplinarity, defined as the process of transcending disciplinary borders and integrating disciplines, the present purpose is best served by describing more precisely the nature of the process and how it unfolds in practice. There are many ways of mapping the interdisciplinary research process, a process that ranges from identifying disciplinary competencies to setting up a dialogue between them, and even to involving in the process lay actors from outside the scientific world. The works that review the literature on the interdisciplinary approach referred to earlier include, for example, various graphic representations of varying degrees of complexity, which seek to portray the process of collaboration between disciplines visually.[4] For the purposes of our analysis, Repko's (2006) summarizing statement was adopted. It, in turn, draws mainly on the work of Thompson Klein (1990), Szostak (2002), and Newell (2007), presented in detail in his book (Repko, 2008) and reproduced in an edited volume (Repko, Newell, & Szostak, 2012). His summary is of relevance in

[4]Incidentally, there is scope for an interesting pragmatic and comparative semiological study on the various imaging tools and techniques used to represent the interdisciplinary process graphically in the scientific literature.

that it attempts to give an explicit formulation of the different stages of the interdisciplinary research process and to describe its properties.

Repko (2006, 2008) identified 10 complementary stages in the interdisciplinary research process (an integrated model of the interdisciplinary research process), which he divided into two macro-phases (A/B). Broadly speaking, these phases are organized around the definition of the problem and disciplinary insights, leading to the integration of these insights and a general understanding of the problem.

A. DRAWING ON DISCIPLINARY INSIGHTS

1. Define the problem or formulate the focus question.
2. Justify using an interdisciplinary approach.
3. Identify relevant disciplines.
4. Conduct a literature search.
5. Develop adequacy in each relevant discipline.
6. Analyse the problem and evaluate each insight into it.

B. INTEGRATING INSIGHTS TO PRODUCING AN INTERDISCIPLINARY UNDERSTANDING

7. Identify conflicts between insights and their sources.
8. Create or discover common ground.
9. Integrate insights.
10. Produce an interdisciplinary understanding of the problem and test it. (Repko, 2006, p. 123)

The interdisciplinary research process is apparently linear in its linking of stages 1 to 10. Based on an interaction between and the integration of several disciplinary perspectives, its aim, is to arrive at an interdisciplinary understanding of the complex question or problem dealt with. In terms of Thompson Klein and Newell's (1997) definition, interdisciplinarity is the practice of integrating several disciplinary perspectives and contributions (see Repko, 2007).

> A process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession and drawing on disciplinary perspectives and integrating their insights by producing a more comprehensive understanding. (Thompson Klein & Newell, 1997, pp. 393–394)

Figure 1 portrays the overall structure of the interdisciplinary research process as seen by Repko. Although the process is presented as a unidirectional succession of complementary stages (see the unidirectional arrows in Figure 1), Repko (2007) noted that the unfolding of the

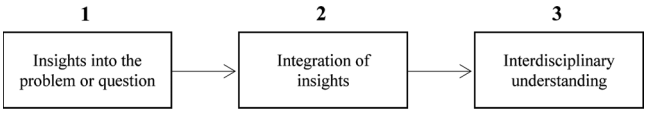

FIGURE 1 The interdisciplinary research process (Repko, 2008, p. 21).

interdisciplinary research process involves potential feedback, iterativity, and negotiation mechanisms that are capable of introducing flexibility into the procedure. He also drew attention to the tension between the different specialist perspectives inherent in scientific communities and their integration in a common analytical perspective on a shared problem. Underlying these nuances, the basic idea that remains is that of a research process organized in different stages that are capable of regulating the manner in which it unfolds. A relatively standard research procedure is discernible in the background (from the formulation of a problem, and questions and hypotheses to be researched, to methodological choices and the analysis and interpretation of results)—in other words, a process divided into stages that are indeed recursive, but a process that is, nonetheless, firmly established and oriented toward the twin goals of explanation and understanding (among the many textbooks devoted to research methodologies; see, notably, Creswell, 2008). This kind of approach is obviously commendable and a necessary one for scientific and pedagogical purposes, if only to meet the needs of those researchers who wish to engage in interdisciplinary research equipped with a research design[5] and a project rationale that is relatively stable and shared by the academic community. In any case, in their work intended for publication and their grant applications to funding bodies, researchers are usually judged according to a set standard requiring the research process to be divided into clearly defined, programmed stages (see Figure 2).

As can be seen from the sequential procedure proposed by Repko (2008), stages 7 (*Identify conflicts between insights and their sources*) and 8 (*Create or discover common ground*) suggest the possibility of a potential clash between disciplines and the fact that researchers are required to create or discover common theoretical or conceptual ground: "Creating common ground is essential preparation for resolving conflict, finding new meaning, and combining or integrating disciplinary insights" (Szostak, 2012, p. 7). Referring to Root-Bernstein (1989), Szostak (2012) also took care to point out that revolutionary scientific discoveries in Kuhn's (1962) sense, are

[5]As the latter term suggests, the *research design* involves, at the same time, the conception of a project, the outlining of a plan of where it is expected to lead, and the drawing of the trajectory or journey. This is, in fact, the meaning of the corresponding Italian term *disegno*, which denotes in Renaissance art theory both the project (the design or idea; French *dessein*) and the drawing (*dessin* in French,) that represents it.

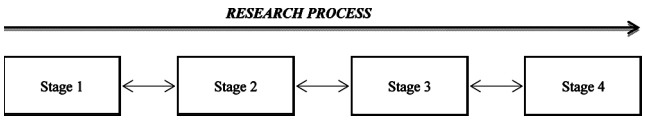

FIGURE 2 "Standard" research process.

often the result of connecting ideas that have their origin in different disciplines. This brings us closer to a form of *interdisciplinary understanding*, which can be described as follows:

> The capacity to integrate knowledge and modes of thinking drawn from two or more disciplines to produce a cognitive advancement—for example, explaining a phenomenon, solving a problem, creating a product, or raising a new question—in ways that would have been unlikely through single disciplinary means. (Boix Mansilla, 2005, p. 16, cited in Repko, 2007)

Next is a thorough exploration of the idea of a *cognitive advancement*, which is made possible by working outside disciplinary boundaries. This involves questioning more closely the interdisciplinary research process, to assess how big a role can be assigned to the unexpected, which is capable of intervening at any stage of the above-described process and of even reconfiguring it through serendipity and diversion.

SERENDIPITY: A DRIVER OF INTERDISCIPLINARY RESEARCH

Opening Oneself to the Unexpected

The concept of serendipity was coined by the British writer, Horace Walpole (1717–1797), in a letter written in 1954 to refer to the art of discovering things "by accident and sagacity while in pursuit of something else" (cited in Van Andel & Bourcier, 2009, p. 27). The concept is an echo of the Persian folktale by Amir Khusrau (1253–1325), *The Peregrinations of the Three Sons of King Serendip* (1927, p. 84, cited in Van Andel & Bourcier, 2009, p. 22),[6] in which—to complete their education—hero-princes roam the world, discovering unexpected clues from which they construct hypotheses about things of which they have no previous knowledge. This happens, for example, in the famous camel story, in which they describe, in accurate detail, a camel they have never seen before. This style of reasoning based on clues also calls to mind the adventures of the eponymous hero in Voltaire's (1694–1778) *Zadig* (1747, p. 37–40), who evokes the "profound and subtle discernment" that comes into play when one is confronted with a "quirk of Providence" (p. 37–40). Discoveries through serendipity are thus associated with the type of reasoning that Peirce (1839–1914) called *abduction*, which complements deduction and induction. Abduction involves a more intuitive and exploratory way of reasoning, which allows one to provide the best explanation possible of a surprising and unexpected fact (Peirce, 1965). The approach is similar to the "detective's method," in Umberto Eco's sense (1992, p. 272), through which the researcher, when confronted with a series of apparently unconnected facts, tries to confer on them an overall intelligibility by assembling them in a coherent sequence.

Making oneself cognitively available to confront the unexpected or accidental is a necessary, but not sufficient, condition for the production of new ideas, in the sense that the researcher must also demonstrate sagacity and be capable of analyzing and understanding the surprise effect so as to exploit it for truly creative purposes. "Having the capacity to be surprised when it matters is the beginning of the mind's journey of discovery," as Pasteur declared in 1883 (1922, p. 370); in other words, it is the step that sets in motion an exploratory process that must then be exploited by reason. Pasteur's comment in reference to the chance discovery of electromagnetism by Hans Christian Oersted, neatly sums up the spirit of work involving serendipity: "Chance favours only the prepared mind" (Pasteur, 1854/1937, p. 131). Hence, serendipity is a form of "happy coincidence," to echo the eloquent subtitle—"*Le Hasard Heureux*"—of the collaborative work on serendipity edited by Bourcier and Van Andel (2011). Examples of discoveries made through serendipity abound in science (medicine, chemistry, mathematics, physics, sociology, anthropology, law, management, and urban planning), the arts (literature, music, theater, and painting) and everyday life: from X-rays to radioactivity, aspirin, insulin, Viagra, DNA, Velcro, and the Post-It, not forgetting *tarte tatin*, Coca Cola, abstract art, and so on (for a collection of cases of serendipity and a suggested typology, see Van Andel & Bourcier, 2009). In each case, the subtle blend of unexpectedness, chance, and sagacity is brought into play, leading to the successful discovery of things while in pursuit of something else.

The discovery of Super Glue is a good illustration of the serendipity process. This example is also given by Lubart in his book on creativity (2003). Researchers employed by the American firm Dow were assigned the task of inventing and testing chemical compounds for protecting the windscreens of airplanes by strengthening their resistance to particles in the air. After applying substance 401, they had to measure the possible deflection of light that might be caused by the substance in question, which carried the potential risk of distorting a pilot's vision. On concluding this stage of the test, much to their dismay, the researchers realized that they could

[6]There are two English editions of the folktale: Remer (1965) and Hodges (1964).

no longer detach the very costly measuring equipment. After several unsuccessful attempts, they decided to call in their boss, Harry Coover (1917–2011), who had a doctorate in chemistry. They explained to him the problem they had unwittingly caused through their ill-fated experiment, fearing that they had irreparably damaged the equipment. The equipment was, indeed, no longer usable, but when faced with this unexpected effect of using substance 401, Coover displayed some sagacity and imposed a very different reading on the ill-fated experiment. By a happy coincidence, the group of researchers had unknowingly and unintentionally assembled the conditions for discovering the most powerful glue ever produced—Super Glue—a glue capable of bonding metal and glass. Under Coover's initiative, the Dow Department actually changed its mission, channelled all its efforts into developing this new glue with its astonishing properties and abandoned its attempts to improve windscreen resistance. On the same subject, another case of serendipity should be cited: the accidental discovery by Spencer Silver (1940–) in 1970 of an adhesive that sticks without sticking, which would eventually lead to the invention of Post-It notes. The properties of this glue are in a sense the reverse of the hyper-resistant properties of Super Glue, but the discovery process is a very similar one. During tests and experiments with various monomers, Silver Spencer discovered a new adhesive polymer by chance, which *sticks without sticking* and only does so in one direction.

These examples of experiments involving serendipity suffice to show that, when confronted with the unexpected, a researcher must be capable of unscrambling the potential for innovation and of exploring new avenues of research; he must be capable of decentring in relation to a strictly controlled and preestablished research protocol. In this type of situation, the researcher is willing to defy the disciplinary expectations that normally guide the (re)production of standard scientific practice (Kuhn, 1962). Absolute respect for conformity to the theories, concepts, and methods peculiar to a cloistered scientific community would, in the circumstances, only generate resistance to what is new and to discovery (Barber, 1961). An inability to reconfigure the way in which the apparently linear research program unfolds would certainly result in the unexpected being perceived as nothing more than a failure, entailing an automatic restart—and one that cannot be questioned—of the process in question. In this case, chance would not qualify as serendipity. On the contrary, one would, in these circumstances, speak of an unhappy coincidence, or of a case of *zemblanity* (an allusion to the imaginary island of *New Zemble* in Siberia), a world away from Serendip, according to the concept of literary provenance proposed by another English writer, William Boyd (1952–), (p. 203). in his novel *Armadillo* (1998). Here, the art of making unexpected discoveries is counterbalanced by the faculty of systematically making "unhappy, unlucky and expected discoveries by design that bring nothing new" (p. 203). The blindness of a disciplined[7] stubbornness, which prevents exploration of the new, corresponds to the subtlety and clear-sightedness of the sagacious mind on the island of Serendip.

Boosting Interdisciplinarity: The Art of Diversion and Bifurcation

If the goal is to make room for the unexpected in the interdisciplinary research process, the linear connection between its different stages must be reconsidered. In the same vein as Figure 1, the canonical ('standard') view of a research procedure can be depicted as in Figure 2.

According to the hallowed expression, researchers very often follow a protocol (in the field and in the laboratory), that is to say, they try more or less to deploy, in their way of working, a theoretical and methodological procedure, on the basis of which—and respecting its different stages—they expect to obtain certain results. Although the strictly linear perception of the research is often subject to qualifications by both the researchers themselves and in textbooks on methodology, and although the effects of iteration, feedback, and recursive loops are taken into account, as noted recalled earlier, it still remains the case that, when the unexpected appears on the scene—and is given serious consideration—the research process in question is liable to be radically reconfigured. What happens to the process when an unexpected idea, concept, fact, or piece of data suddenly appears in the research process? A researcher who detects this unexpected effect and who is capable of applying his sagacity in a spirit of discovery and innovation deliberately diverts the course of the research. Owing to the serendipity effect, he introduces into the process a transgressive bifurcation, by changing the cognitive and temporal systems. He or she crosses a threshold, a point of bifurcation, and, spurred on by this, is both ready to display a certain lack of discipline and capable of exploiting the unexpected in order to develop new research possibilities. The creative diversion that surfaces at some point in the research process is summarized in Figure 3.

In retrospect, Merton's (1968)[8] definition of serendipity becomes, at this point, particularly illuminating:

[7] *Discipulus* in Latin denotes precisely the pupil or disciple who submits to the rules of discipline, performing acts of obedience and submission. *Discipline*, which derives from the Latin *disciplina*, also refers to a whip made of thin cords or small chains and used as an instrument of penance. One prevents others or oneself from stepping outside a preestablished framework by ordering, administering, or disciplinary beatings as a punitive measure of control and/or of coercive self-discipline. On this point, see Origgi and Darbellay (2010).

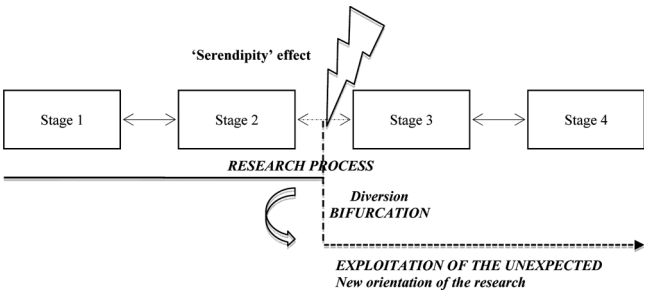

FIGURE 3 Serendipity effect and diversion.

> 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. … The datum is, first of all, unanticipated. A research directed towards the test of one hypothesis yields a fortuitous by-product, an unexpected observation which bears upon theories not in question when the research was begun. Secondly, the observation is anomalous, surprising, either because it seems inconsistent with prevailing theory or with other established facts. In either case, the seeming inconsistency provokes curiosity; it stimulates the investigator to "make sense of the datum," to fit it into a broader frame of knowledge. (p. 158)

By situating itself within a broader frame of knowledge, interdisciplinary work should, precisely, draw attention to unanticipated, lateral observations that relate to theories not in question when the research was begun and which are capable—through their surprise effect—of creating a discordance[9] (an abnormality), one that is productive of something new, between widely held and apparently established theories in a given scientific field. This strategic importance of exploiting the serendipity effect allows the transition from the emergence of a new idea—its bursting forth—to the stimulation and intensification—the boosting—of the interdisciplinary research process in that the researcher significantly modifies the way in which the program unfolds, while at the same time speeding up the circulation of concepts, ideas, theories, and methods beyond the compartments of disciplines. To boost the interdisciplinary research process is, therefore, to enable exchanges between disciplines to happen more quickly and more extensively. This increased interdisciplinary activity is not confined to joining up or integrating two or more disciplinary viewpoints; more than that, it operates by means of a creative diversion conducive to scientific discovery in a context that transcends individual disciplines. The chances of innovation are increased, as researchers decenter in relation to their original discipline(s). Certainly in science, innovation is often the result of hybridization between theories, concepts, and methods belonging to different disciplines, in a logic of "creative marginality," to use Dogan and Pahre's (1990) title. The researcher, competent in his own discipline, also demonstrates the cognitive agility to divert his attention (away from his disciplinary ethnocentrism) and tune in to concepts, theories, and methods that do not routinely feature in his scientific field, but which allow him—by means of judicious borrowing and constructive analogies—to boost his thinking, to steer his research in a new direction, and to develop insights into the objects being researched.

The nomadism of concepts is a good illustration of how knowledge is put into circulation beyond disciplinary boundaries. Bifurcations by means of borrowings, transfers, and hybridization build bridges between disciplines. The collaborative work edited by Stengers (1987) clearly shows how the concepts *correlation, law, calculation, problem, selection*, and *complexity* circulate between genetics, economics, logic, biology, ethnology, philosophy, history, and psychoanalysis. These "conceptual migrations" (Fedi, 2002, p. 5) are all "fortuitous forms of contamination" (Dumas, 1999, p. 51), which enable knowledge to develop and new theoretical horizons to be discovered (Darbellay, 2012). Strategies involving borrowing, transfer, and nomadism often operate through analogies and metaphors applied to ideas, concepts, or theories that were, nonetheless, tied to apparently unconnected disciplinary fields (Hofstadter & Sander, 2013; Sander, 2012). This was the experience of Pål Nyrén (1955–)[10] and his team, for example, who invented a new method of sequencing DNA that is quicker, simpler, and less costly: the pyrosequencing method (Ronaghi, Uhlén, & Nyrén, 1998). The creative process consisted in working by analogy—in this instance a fortuitous" analogy, based on observation of the firefly's ability to produce light (bioluminescence). The technique allows DNA to be sequenced by a chemical process: The sequencing produces light in much the same way as fireflies do, which is captured by ultrasensitive cameras. This invention has revolutionized DNA sequencing, by enabling it to be done much more quickly and by recording voluminous amounts of extremely important information, however the researchers had

[8]See also the seminal work of Merton and Barber published in 2004 by Princeton University Press: *The Travels and Adventures of Serendipity* (1958), as well as Merton (1945).

[9]The introduction of a gap, a creative disparity evokes the notion of *lateral thinking*, developed from the 1960s onward by Edward de Bono (1973). The *lateral thinker* is capable of modifying his preconceptions about knowledge and of thinking at the margins (outside the box), to develop new ideas.

[10]Professor of Biochemistry at the Royal Institute of Technology in Stockholm. He is recipient of the European Patent office's European Inventor Award 2013 in the Small and Medium-Sized Businesses category.

been looking more toward techniques related to radioactivity. Given that, with this technique, the speed with which a genome can be sequenced has more than doubled every two years since 2003, it has also boosted sequencing. Pål Nyrén, a specialist in biochemestry, had no particular expertise in the discipline of entomology, nor was he working specifically on bioluminescence, but he was able to exploit his unexpected encounter with the light-emitting properties of fireflies, branching off from his research protocol with positive results.

The researcher who is willing to open his mind to the kind of unexpectedness that produces new knowledge, allies, as it were, Greek *mètis* (intelligence as cunning) to the skilfulness of Latin *métis* (from *mixtus*, 'mixed'), which encourages hybridization, the mixing of two or more disciplinary theories or concepts. In our reading of the interdisciplinary process, the researcher should, therefore, not only mobilize a plurality of disciplinary viewpoints (the disciplinary insights of Figure 1) and insert them into a chain of successive stages oriented toward the resolution of a problem (see Figure 2), he should also be prepared to confront the unexpected and make it work at the very heart of interdisciplinarity (see Figure 3).

Peirce (1965), quoted earlier, was surely right to speak of "abductive suggestion," (p. 375) a flash of insight that acts like a flash of lightning in the mind of the researcher, who succeeds, through a creative insight, in developing new hypotheses for a comprehensive understanding of the phenomenon being studied. Ultimately, interdisciplinary research is not only relevant in the context of solving problems by drawing on different disciplinary competencies; it should also be called on to play a meaningful role when it comes to scientific discovery. It would then be a matter of developing cognitive competencies capable of revealing the failures in understanding the complexity of research objects and of uncovering new problematics (problem finding) by going further than a simple critical review (problem shaping or framing) of a research issue and immediately revisiting the problem-solving process in question (see Getzels & Csikszentmihalyi, 1976; Runco, 1994). The problem-solving approach and the creative approach come together in interdisciplinary work to yield the mixed approach of *creative problem solving* oriented toward discovery and innovation (Osborn, 1940; Parnes & Harding, 1962).[11] Interdisciplinarity is, therefore, certainly grounded in *convergent thinking*, which draws on established pluridisciplinary competencies and existing knowledge in a climate of expectation on the part of the researchers for the purpose of developing a series of solutions to a problem and selecting just one of them as the only correct one; but it also has to resort to *divergent thinking* (Guilford, 1967), which frees itself from knowledge that is already established and from traditional kinds of reasoning so as to find—with imagination and in a spirit of discovery—innovative, even revolutionary, solutions to a given problem.

CONCLUSION

The interdisciplinary research process—built on disciplinary competencies, which, at the same time, need to be transcended and integrated in a broader perspective—can find an interesting and appropriate ally in the phenomenon of serendipity. In tackling the question of interdisciplinarity from the angle of scientific discovery and the scientific imagination, a place is provided for the unexpected in research, which is then capable of being reconfigured and of boosting new theoretical, conceptual, or methodological exploration outside disciplinary limits. Work at the boundaries of disciplines, however, amounts to more than the mythical flash of inspiration of Archimedes's *eureka*; on the contrary, it is part of a flexible process that goes through a number of phases: incubation, progression and abductive reversion, bifurcation, analogical hybridization, and stabilization. To return for a moment to Veyne's observation, which was used as an epigraph (1983), although it no doubt takes a touch of genius to get out of one's disciplinary jar or to innovate from inside it, one must also adapt to the mindset of producing new ideas as part of a team. Although creativity clearly depends on individual competencies, and sometimes exceptional ones, like those of Freud, Einstein, or Picasso, according to the arguments put forward by Gardner (1993) in his study on the different forms and spheres of creativity, it remains the case, nonetheless, that the collaborative dimension is increasingly a factor in the today's context of the internationalization of research.

Pursuing the analysis and understanding of the interdisciplinary research process as a creative process will have everything to gain in future from mobilizing and cross-fertilizing the advances made in both individual and collaborative research on interdisciplinarity[12] with advances in the work on creativity in the arts and sciences (see Gardner, 1988; Lindauer, 1998; Sawyer, 1998; Thiessen, 1998). *Interdisciplinarity, creativity,* and *collaboration* are three keywords that will undoubtedly become increasingly inseparable. In any case, they find a stimulating echo in the digital turning point being experienced by scientific practice today.

[11]Osborn is also well known for having invented *brainstorming* as a method of solving problems from a creative point of view.

[12]The work done by *Science of team science* (SciTS) is particularly relevant in this context. See, for example, Fiore (2008) and Stokols, Hall, Taylor, and Moser (2008).

This approach borders on interdisciplinarity 2.0 in the context of the digital humanities (Darbellay, 2013); in other words, it is an approach located at the interface of work on interdisciplinary research and the new modes of producing, processing, and disseminating knowledge. Interdisciplinarity, as a new way of thinking in the digital age, is in a kind of happenstance situation, a way of thinking and of conducting research that is in the right place at the right time, in the sense that the circulating of ideas, concepts, theories, and methods is closely attuned to the possibilities for exchanges, networking, and collaboration inherent in the new digital technologies. Serendipity as a method of exploration and discovery is, moreover, increasingly discussed in connection with surfing the web for information. It certainly offers enormous potential for discovering new and unexpected information, but, equally, it must be used with rigour and restraint and in a frame of mind primed to be receptive.

As for just where serendipity-inspired interdisciplinarity shall find expression, whether in live, face-to-face situations or virtual ones, in conclusion, it would appear worthwhile to raise an open question that merits closer attention: In the university context where knowledge domains, nonetheless, continue to be relatively compartmentalized, is it, in fact, productive to set up facilities specifically for creative interdisciplinarity between disciplines and subdisciplines, a kind of "institutionalized serendipity," to borrow Merton's expression (Merton & Barber 2004, p. 267)? And in this innovative institutional context what would be the impact on traditional researchers' careers, with reference to the work of Diaz de Chumaceiro (1998, 1999a, 1999b, 2004)? In this context, the researcher is also called into question: Will the polymath researcher (Root-Bernstein, 2003; Root-Bernstein, Bernstein, Garnier, 1995) with expertise in several disciplines find his niche in the research system as it stands at present, or will he be forced to become a super-specialist while at the same time working collaboratively, either within his own discipline or with other specialists?

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