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On Serendipity in Science:

Discovery at the Intersection of Chance and Wisdom

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Abstract (226 words):

'Serendipity' is a category used to describe discoveries in science that occur at the intersection of chance and wisdom. In this paper, I argue for understanding serendipity in science as an emergent property of scientific discovery, describing an oblique relationship between the outcome of a discovery process and the intentions that drove it forward. The recognition of serendipity is correlated with an acknowledgment of the limits of expectations about potential sources of knowledge. I provide an analysis of serendipity in science as a defense of this definition and its implications, drawing from theoretical and empirical research on experiences of serendipity as they occur in science and elsewhere. I focus on three interrelated features of serendipity in science. First, there are variations of serendipity. The process of serendipitous discovery can be complex. Second, a valuable outcome must be obtained before reflection upon the significance of the unexpected observation or event in respect to that outcome can take place. Therefore, serendipity is retrospectively categorized. Third, the primacy of epistemic expectations is elucidated. Finally, I place this analysis within discussions in philosophy of science regarding the impact of interpersonal competition upon the number and significance of scientific discoveries. Thus, the analysis of serendipity offered in this paper contributes to discussions about the social-epistemological aspects of scientific discovery and has normative implications for the structure of epistemically effective scientific communities.

Serendipity is a category used to describe discoveries that occur at the intersection of chance and wisdom. To quote the word's inventor, Horace Walpole, it describes "discoveries [made] by accidents and sagacity, of things [the observers][1] were not in quest of" (1754, quoted in Merton and Barber 2004, p. 2). This paper brings together the work of philosophers of science with results of the empirical study of experiences researchers and others have had of serendipity, including the reflections of practicing scientists in diverse fields. I show that serendipity in science is best understood when looked at within the broader context of the scientific community, rather than narrowly through the lens of individual experience. At the level of the individual, serendipity points to a discovery marked by a surprising insight; at the community level, the role of epistemic expectations—both enabling surprise and determining the response to surprise—is illuminated. In turn, my approach has implications for how the scientific community ought to be structured, in order to maximize the benefits of serendipitous discovery for scientists, science and society.

I argue that serendipity is an emergent property of scientific discoveries, describing an oblique relationship between the outcome of a discovery process and the intentions that drove it forward. This definition arises from the close examination of several key features of serendipity relevant to its impact on the practice of science. These features together provide a paradoxical picture of serendipitous discovery: it requires both luck and skill, and is both unpredictable and yet can be cultivated. The purpose of this paper is to demonstrate that, when the context of the scientific community is properly taken into account, the individual experience of serendipitous discovery is no longer paradoxical. In communities that allow diverse members opportunities to contribute to the production of knowledge, there will both be more opportunities for serendipitous discovery and community members will develop the skills necessary to take advantage of those opportunities.

The first three sections of the paper address the relevant features of serendipity in science. First, serendipity has many variations. Analyses of serendipity commonly focus on an insightful, cognitive connection made by a 'serendipitous' individual. However, serendipity as experienced by scientists and by others consists of multiple kinds of connections, including social relationships and timeliness. Further, serendipitous discovery is a process rather than an event, and can be marked by several intersections of chance and wisdom that enable the valuable outcome. Second, serendipitous discovery is profoundly contingent upon contextual factors, beyond the insight of the serendipitous individual. Because it is both contingent and inherently unpredictable, serendipity can only be used retrospectively as a category to describe scientific discoveries. Further, the insight of the individual is insufficient for bringing about a serendipitous, scientific discovery—such discovery processes are also dependent on environmental factors, and the structure of the community of which the individual is a member. It is within this complex network of interacting factors that the three elements of serendipity come together, and it is from this complex network that serendipitous discovery emerges. Third, serendipity occurs when the limitations of epistemic expectations are exposed: a discovery is serendipitous because it arises from an unexpected source of knowledge, or because knowledge is produced in an unexpected way. Specific skills, in fact, are associated with serendipitous discovery, but the exercise of these skills is dependent on external factors, such as timeliness and community support, for its success. By establishing these features, I provide a defense of my definition of serendipity. In the fourth and final section, this paper makes an explicit contribution to ongoing discussions in philosophy of science, pointing to one

[1] Walpole is specifically referring here to the Princes of Serendip, characters in a fairy tale who inspired him to label this phenomenon 'serendipity' because of how they make valuable use of accidental observations.

implication of my analysis for the structure of science. My understanding of how serendipity works in science grounds a normative framework that affirms the value of early publication, both for individual scientists and for science itself.

1. Variations of Serendipity

In analyses of serendipity, the focus is often on the serendipitous individual's insight that an unexpected observation or event has value, despite its being anomalous or even in conflict with prevailing knowledge. A classic example is the narrative of the gregarious Barry Marshall, who stubbornly persisted against the grain of prevailing wisdom to convince gastroenterologists that ulcers could be caused by bacteria. This ability to perceive the potential value of an unexpected observation is frequently associated with the intellectual capacity of an individual to make some sort of "connection" between the observation and previously held knowledge. Often this is cashed out in light of Louis Pasteur's famous dictum, that "chance favours only prepared minds" (1854, quoted in van Andel 1994, pp. 634-5).

Many theorists of serendipity have given a primarily cognitive account of the wisdom involved in recognizing potential value in the unexpected. James Austin (2003) defines what he calls the "Pasteur Principle": "Some special receptivity born from past experience permits you to discern a new fact or to perceive ideas in a new relationship, and go on to comprehend their significance" (p. 76). Miguel Piña e Cunha and colleagues (Cunha et al. 2010) take up Arthur Koestler's (1964) term of "bisociation" as the "functional basis for metaphorical thinking…Bisociation entails an exercise of intuition, the intuitive recognition of possibilities…when ideas are combined in an original way" (Cunha et al. 2010, pp. 321 & 323). Similarly, Mark de Rond (2014) suggests that the key component of serendipity is an intellectual capability for making "'matching pairs' of events…that are *meaningfully*…related" (p. 1, emphasis his). Other theorists have used the Peircian term "abduction" to capture the kind of inferential reasoning that goes into evaluating the potential value of an unexpected observation (e.g.: Darbellay et al. 2014, p. 5; van Andel 1994, pp. 635*ff*).[2] According to Paul Thagard, the serendipitous moment in a scientific discovery is marked by a "conceptual combination" (Thagard 2012, p. 392).

Such intellectual connections are described by Gary Fine and James Deegan (1996) as instances of "analytical serendipity." Analytical serendipity is only one of three categories of serendipity Fine and Deegan identify in the autobiographical narratives of ethnographers. They also identify two other categories, "temporal serendipity" and "serendipity relations." Temporal serendipity describes the inclusion of a dramatic but unexpected event in an ethnographer's tale, one that allowed the narrator to participate in aspects of a culture they would otherwise have missed altogether.[3] The category of

[2] Of course, in philosophical discussion about the logic or rationality of scientific discovery, there is a deep and complicated debate concerning abduction (see work by Peirce, Paavola, Hanson, Hintikka, for example). How well abduction works as a description of the reasoning involved in some cases of serendipity (see the following paragraphs) is a topic I pursue elsewhere, and is outside of the scope of this paper.

[3] This is also frequently called *synchronicity* in the serendipity literature, following Jung: "simultaneous occurrence of two meaningfully but not causally connected events" (as quoted in Liestman 1992, p.527). Daniel Liestman's (1992) use of synchronicity as one category of serendipity in library research is picked up by several others, from fields such as computer-human interaction (Kefalidou & Sharples 2016), education (Nutefall & Ryder 2010) and information studies (Foster & Ellis 2014). Synchronicity is also appealed to by organizational and management theorists (see Cunha 2005 for further references). However, I follow Lawley and Tompkins (2008), who draw a distinction between synchronicity and serendipity, because the former is recognized immediately whereas the latter is not (see section 2).

serendipity relations describes “the unplanned building of social networks” (Fine & Deegan 1996, p. 438). It includes the people we meet unexpectedly, who turn out to be sources of valuable knowledge or who lead to further valuable connections (Fine & Deegan 1996, p. 440). Temporal serendipity and serendipity relations are instances in which serendipity goes beyond the cognitive: connections made between people, or ones being present at the right time and in the right place, can just as well lead to valuable discoveries.

Examples of serendipitous connections that are temporal or social, rather than or as well as intellectual, are found throughout contemporary descriptions of serendipitous science. A serendipitous discovery process in science can involve multiple kinds of serendipity. Tales of serendipity often include the details of life that led individuals to be in the right time, place and circumstances to make a discovery.

For instance, the story of Marshall’s serendipitous discovery of the bacterial cause of stomach ulcers tends to focus on his role as spokesperson for his own discovery. However, Paul Thagard provides a detailed recounting of the discovery in which we see how Marshall’s good fortune in having the right social connections and available resources enabled him to succeed (Thagard 1998a, 1998b). In James Estes’ (2016) scientific autobiography, the author recounts several different kinds of serendipity. At times, Estes happened to meet the right person, with whom he could continue his work (pp. 101, 108, 116). Some people he met guided his research in a distinct way (pp. 29, 37, 191). Circumstances put him in the right place and time to make key observations (pp. 28, 108, 148). External events also affected the path he took as a scientist (pp. 21, 33, 167, 203-4). When reflecting upon these instances in his past, Estes sees them—and, consequently, the scientific discoveries they enabled him to make—as serendipitous (pp. 3, 230).

Howard Gest (1997) offers another example, when he notes the importance of an unexpected social connection between labs in the isolation of vitamin C. A former graduate student (Joseph L. Svirbely) of Charles King who had been working with King on the problem of scurvy wound up, via “a serendipitous event,” working in the lab of Albert Szent-Gyorgyi in Hungary. It was this unexpected social connection that led to the testing of Szent-Gyorgyi’s sample of a chemical he had isolated and called hexuronic acid, to confirm it was indeed vitamin C. Consequently, this unexpected social connection led to Szent-Gyorgyi’s receiving a Nobel Prize for that work (Gest 1997, pp. 22-24). In Gest’s (1997) words, Svirbely the PhD student had become an “accidental agent,” connecting the research happening in otherwise isolated labs (p. 24).

Hindsight has the effect of reifying a complex process as a linear sequence of events, and serendipity narratives often rhetorically trace the origin of a discovery to a “magic moment” in time (de Rond and Morley 2010, p. 7). Likewise, scientific processes are often only retrospectively recognized as leading to discovery (Fleck 1979). Thomas Nickles points out that this retrospective classification of a particular series of events as leading to discovery can have a rarefying effect on our perception of the originating event:

> What we retrospectively interpret as revolutionary breakthroughs typically begin life as rather normal work. Over time, by telescoping historical development, scientists whiggishly invest these charmed cases with far more meaning than they originally possessed…Most analysts of scientific discovery fail to notice that much or most of what we count as “the discovery” is actually accomplished in the reworking and refinement that occurs in the years and decades *following* the original work. (Nickles 1997, pp. 128-129, emphasis his).

As Nickles notes, events that follow the “origin moment” have as much to do with making the discovery as the moment itself. In fact, when a discovery narrative is told there is often a choice to be made as to which event attributes the property of serendipity to the discovery. The story of penicillin’s discovery, for instance, contains multiple chance events and coincidences, and the discovery was not a direct or even predictable result of Alexander Fleming’s insight in shielding the infamous petri dish from the wash.[4] As Gest comments regarding the narrative of the vitamin C discovery:

> The fateful connections and sequelae involving King, Svirbely, and Szent-Gyorgyi were, in fact, quite complicated and even now, difficult to sort out…A number of serendipic [sic] events were involved in the vitamin C story, but none of them can be said to be *the* crucial event or “accident.” (Gest 1997, p. 23-24, emphasis his).

In sum, serendipity in the practice of science is more ubiquitous than momentous. Robert Merton pointed to this first when he described what he called the “serendipity pattern”: “observing an *unanticipated, anomalous and strategic* datum which becomes the occasion for developing a new theory or for extending an existing theory,” a “*fairly common experience*” (Merton 1948, p. 506, emphasis his, then mine). I argue that it not only describes the greater-than-average-value discoveries that arose with the help of chance, such as penicillin, but also the networks of accidental connections later recognized as valuable (Copeland 2015; see also McCay-Peet & Wells 2017, p. 99). These include connections between ideas, people, places, experiences, and more. When such connections happen during a discovery process, any one of them may lead to the categorization of the discovery itself as serendipitous. Thus, a process of serendipitous discovery is likely to involve participation from multiple scientists, in one way or another, and to extend across time. In contrast to the individualistic depiction of serendipity as a “flash of insight” then, we have a picture of serendipity as occurring within a community, involving networks of individuals and interactions (McBirnie & Urquhart 2011).

2. Retrospectivity & Emergence

Thagard provides an excellent case study in his detailed description of one of the more popular examples of serendipity in the literature, the discovery of *H. pylori* and its relationship to ulcers, for which Barry Marshall and Robin Warren were awarded a Nobel Prize (Thagard 1998a, 1998b). Thagard himself uses serendipity to describe two distinct events in the discovery process as a whole: the observation of bacteria in the stomach, and the discovery of how to cultivate the bacteria in the lab.

Warren was not searching for bacteria in the stomach when he found it, during the course of his everyday work as a pathologist. As Thagard comments, “he just happened to examine gastric specimens with sufficient microscope magnification to make bacteria visible” (1998a, p. 114). At the time this observation was made, the stomach was thought to be a sterile environment in which bacteria could not survive, and so the observation was unexpected. Thus, the discovery of *H. pylori* bacteria in the stomach by Warren was serendipitous. For Thagard, the value of this serendipity is that it generated questions

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[4] There are many chance aspects of even this observation, including the perfect temperature fluctuations in London at the right time, an open door to a stairwell, and Fleming’s vacation (Diggins 2003). Chance marked the path to penicillin’s mass-production as well—to name one instance, lab assistant Mary Hunt was at the local market when she picked up a moldy cantaloupe, which led to the discovery of a better medium for penicillin’s production, despite the hundreds of samples sent from afar to the lab for just that purpose. The insightful assistant in this case was, however, rewarded with a nickname—‘Moldy Mary’—rather than a Nobel Prize.

for the curious Warren, who then pursued investigation of the bacteria with the help of a gastroenterologist, Marshall. Serendipity here is a surprising observation that leads to a new direction of inquiry.

Similarly, serendipity played a role in Marshall's later discovery of how to cultivate the bacteria in the lab. Attempts to cultivate it repeatedly failed at first. It was then accidentally discovered that the forty-eight hours given to allow growth was insufficient—the distraction of a busy schedule and the coincidence of a four-day weekend provided the solution, allowing the bacteria five days to cultivate (Thagard 1998a, p. 114). In this case, serendipity is a chance event that leads to an unexpected solution to a problem.

Thagard separates out these serendipity-moments because they are marked by surprise and chance, in contrast to the intentional phases of questioning and search that followed (Thagard 1998a; 2002, p. 90). However, as Alan Baumeister, Mike Hawkins and Francisco López-Muñoz (2010) illustrate in their analysis of the history of serendipity in psychopharmacology, this treatment of a single discovery process as a series of moments can be confusing. For instance, they consider two seemingly contradictory claims made by John Cade, who discovered that lithium was an effective treatment for mania. Cade claimed both that the discovery was *unexpected* and that the *expected* result of a clinical trial in humans was a reduction in mania (Baumeister et al. 2010, p. 265). Baumeister and colleagues resolve this contradiction by breaking the discovery of lithium as a treatment for mania into two, distinct discovery processes—one serendipitous (an unexpected observation that lithium had lethargy-inducing effects on guinea pigs) and one non-serendipitous (the rational pursuit of lithium's therapeutic application in a clinical trial).

However, the observation that lithium had lethargy-inducing effects on guinea pigs was not valuable until its effectiveness in treating mania was recognized; until the 'second' discovery was made, the 'first' discovery was not considered a serendipitous discovery in psychopharmacology. Cade himself may have thought it an interesting and valuable *observation* at the time, but only upon confirming its value to science and medicine did it become an episode in a narrative about a *discovery*, leading to the confusion pointed to by Baumeister and colleagues. As does Thagard, Baumeister and colleagues break a process into serendipitous and non-serendipitous moments, events or discoveries in order to clarify the interaction between intentional and non-intentional aspects of a discovery process. However, these distinctions are misleading when it comes to understanding serendipity itself. In particular, they prevent analysis of two key aspects of serendipity in science, retrospectivity and emergence.

I argue rather that classifying a discovery as serendipitous points to the impact of one or more unexpected events upon a process that is not complete until the valuable outcome has been determined. To understand how serendipity happens we must look at the interconnection between insight, the unexpected event(s) and the valuable outcome together (Copeland 2015; Solomon 2017, p. 5; McCay-Peet & Wells 2017, p. 103). Not only is it often arbitrary to distinguish one unexpected connection as "*the* crucial event," as Gest puts it in the quotation above, but what gives meaning to the moment of surprise—what makes it *serendipitous*—includes the value of the outcome, as well as characteristics inherent in the moment itself.

Consider a case of "serendipity lost"—an unexpected insight that, although wise and marked by surprise, fails to result in a valuable outcome. While these are hard to come by—rarely does one find a publication detailing a discovery that was never made[5]—one example has been described in detail by Bernard Barber and Renée Fox (1958). They tell the tale of the floppy eared rabbits: an observation of a reaction in their experimental rabbit population made by two scientists at almost the same time, both of whom were insightful enough to recognize it was an interesting observation that ought to be followed up. Only one of the scientists, however, actually did follow it up sufficiently to make a discovery about the effects of papain on the cellular structure of the ear cartilage. There was no real difference between the two scientists' original observations, as Barber and Fox point out—both observations were unexpected, and both inspired an insightful curiosity in the observers. What made the difference to the discovery were the events that followed that observation, and the obtainment of the valuable outcome in one case but not the other. As a result, Dr. Kellner was not serendipitous in respect to this observation, driven down other paths of research instead. For Dr. Thomas, the serendipitous scientist in this story, "the planned and the unplanned, the foreseen and the accidental, the logical and the lucky…continued to interact" beyond the original observations to keep him on the path to this particular valuable outcome (Barber & Fox 1958, p. 134).

Thus, serendipity is a category that can only be applied retrospectively to a discovery process, once the valuable outcome has been determined and upon reflection on the now-apparent significance of the relevant unexpected events and insight.[6] One never says, "This is going to be serendipitous"—not only because it often occurs by chance, but also because until the value of the discovery is made clear, the category of serendipity does not yet apply.[7] In fact, empirical research shows that a period of reflection is necessary for the observer to recognize the significance of the chance event and the wisdom of her own insights.

In light of qualitative data acquired through interviews with academic researchers, artists, library users and laypeople, several versions of a process model of serendipity have been developed (Cunha 2005; Lawley & Tompkins 2008; McCay-Peet & Toms 2010; Rubin et al. 2011; Makri and Blandford 2012).[8] These process models all include the outcome as a necessary step in serendipitous discovery. Further, many of them highlight its retrospectivity and the necessity of reflection upon previous events before the category is applied. Consider this version by Stephann Makri and Ann Blandford (2012):

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[5] A possible exception is Alexander Kohn's (1989) book, *Fortune and Failure: Missed Opportunities and Chance Discoveries in Science.* However, as with the example given by Barber and Fox, the 'forgotten' discoveries in this book are only seen as such in light of the discoveries that were (later) actually made.

[6] Given the quotation from Nickles above, one might extend this retrospectivity to many discovery processes, but since it would not extend to *all* processes categorized as discovery processes (since some are indeed intentional, for example, and therefore prospective), 'serendipity' remains a particular classification within that broader category (ie: a kind of discovery process that is recognized retrospectively).

[7] Of course, in some cases this timeline is collapsed, such as when the value of the discovery is clear at the time of observation. One example might be when a collector of fine garden gnomes happens by chance to visit a friend whose neighbor is holding a garage sale and selling a gnome whose value the collector is able to identify immediately. But more often, including in the examples Walpole himself gives and (I would argue) almost always in the case of scientific discovery, multiple steps are required to reveal the true value of the unexpected finding. And still, the gnome collector could not have known her visit to the friend would be serendipitous beforehand (or it wouldn't have been, by definition).

[8] Cunha (2005) and Lawley and Tompkins (2008) developed the first process models through an analysis of case studies and the literature. The later articles cited here refer to studies that confirmed and refined that model via empirical research (i.e.: interviews).

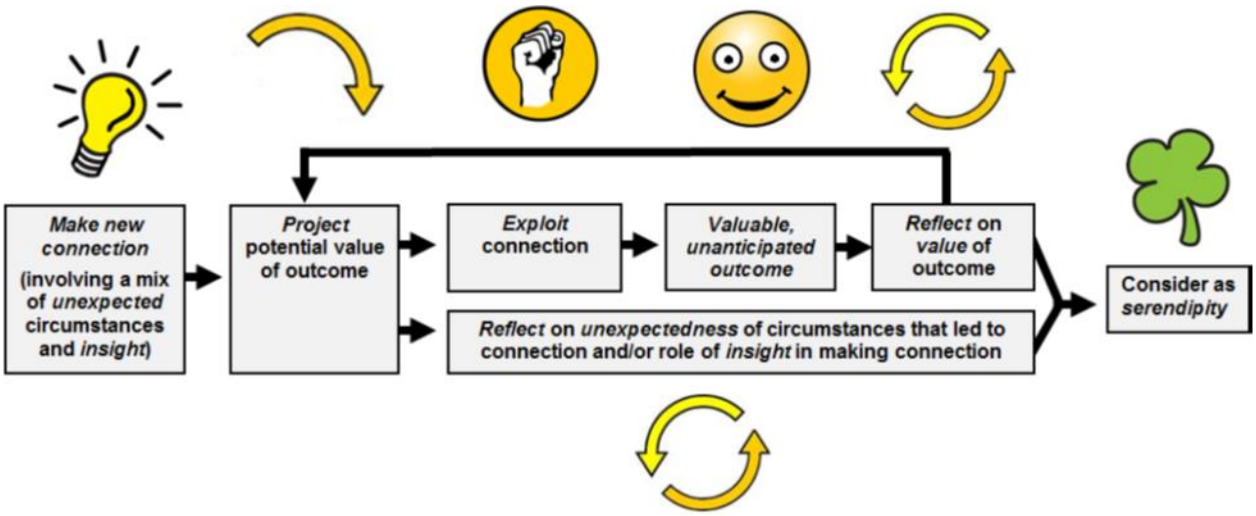

Figure 1: Makri and Blandford's empirical process model (2012, fig.2)

Because of the retrospective nature of the category, the fact an unexpected event, meeting or observation *was* serendipitous is determined by reflection upon the value of the *result* of a *process* during which that event, meeting or observation played a key role. First, note that this process is often iterative, rather than strictly linear (see also Lawley & Tompkins 2008; McCay-Peet & Wells 2017, p. 102). Before the value of the outcome is established, several iterations of "reflect upon the value," "project the value," and "exploit the connection" may occur. Along the way, other outcomes of value may be obtained and there may be several moments in which chance intersects with wisdom. But the process of serendipitous discovery is not complete until a particular outcome is obtained such that it results in the perception of at least one of those moments as unexpectedly valuable *in relation to that outcome.* Only then is the "mix of unexpected circumstances and insight" (together with the outcome) considered an instance of serendipity.

Second, the value assigned to the moment and the outcome together is oblique in relation to the intentions that (initially) drove the underlying process forward. That is, the intentions behind the activity taking place at the time of the unexpected observation or event are only indirectly related to the outcome of the process, the serendipitous discovery. In Walpole's words, "many excellent discoveries have been made by men who were *á la chasse* of something quite different" (1789).

This holds for cases of so-called pseudoserendipity as well. The term "pseudoserendipity," coined by Royston Roberts (1989), suggests that a distinction should be made from "pure serendipity" in cases when the observer may have been seeking the knowledge she accidentally found. One example is Charles Goodyear's discovery of the vulcanization of rubber. The actual discovery was accidental—Goodyear had not planned to heat the rubber compound he was working with when it (accidentally) came into contact with a hot stove. However, he was *in general* looking for a method to enable rubber to withstand the cold, and such a method was revealed by his mistake. Because Goodyear was looking for just such a solution, but found it in an unexpected place, Roberts feels this example does not capture the essence of serendipity (Roberts 1989, pp. 54-55). However, the outcome is still obliquely related to the intentions driving the process—the intentions behind Goodyear's use of the stove at the time did not include a hypothesis about vulcanization. The value of heating rubber was unknown at the time the rubber was spilled and so was determinable only retrospectively, once the effects were observed and their application surmised.

Similarly, as Aharon Kantorovich argues in his book-length treatment of serendipity in science (1993), processes of discovery frequently end in a way unpredictable from the perspective of their origins. Because other scientists will take an observation and work with it, new purposes and new knowledge inevitably arise that do not reflect the intentions of the original observer in making and disseminating the observation itself. The observer, in Kantorovich's words, remains "blind" to the ultimate value of the observation (1993, pp. 153-154). It is this oblique relationship with the intentions driving the underlying process—the reasons behind the actions being taken at the time—that marks serendipitous discovery. The outcome, indeed, *emerges* from the processes and intentions (and other features of the context) at hand.

For instance, take the origin of the word itself, in the fairy tale that Walpole recounted in his 1754 letter to More. The princes of Serendip were on the road to Persia when they made observations that, later, when they encountered a person with a problem (having lost his camel), became useful in solving that very problem. At the time of making the observations, the princes could not have known they would encounter the camel driver who needed that knowledge. Nonetheless, they recognized their observations were interesting and potentially valuable, and readily recalled them when they could be used. A (serendipitous) collaboration between them and the camel driver thus emerged when he presented them with a problem to which they (unexpectedly) had the solution.

An emergent property can be described as novel in the sense that it cannot be reduced to the properties that exist in the underlying process or context from which it arose (Clayton 2006). A popular example is the idea that consciousness "emerges" from the neural networks of the brain. In the tale of the princes of Serendip, the property of serendipity emerges from the *interaction* of the princes' observations with the further context of the camel driver's problem, and not from any properties inherent in the observations (or in the camel driver's problem) themselves.[9] As David Chalmers (2006) points out, however, emergence is used in science and philosophy to express two distinct concepts. What is often called "weak emergence" is defined epistemologically, as the result of a limitation in our understanding of events, objects, and their properties. In contrast, "strong emergence" suggests that the emergent phenomenon cannot be deduced, even in principle, from the properties of the underlying context or process from which it arises. Considering serendipity in light of this debate draws out both why the term applies to serendipity as well as the nature of the role epistemic expectations play in serendipitous discovery.

One might consider serendipity as an example of weak emergence, because it seems that only our epistemic limitations make it unexpected. However, even if it were possible to rationally reconstruct the process involved in some past incident of serendipity perfectly, thereby enabling us to explain (and, in principle, predict) how that event occurred, this does not mean it is not a case of strong emergence (Anjum & Mumford 2017, p. 104). Further, both the state of knowledge in science and the environment in which it is practiced continues to change, and so the complex interaction of factors that enables a

[9] See Anjum and Mumford (2017) for an example of an account of emergent properties as those properties that do not belong to the parts but rather arise from an interaction between parts as novel properties of the whole.

serendipitous discovery to occur in one instance will not be repeated in the next. The ability to explain a causal process when looking backwards does not logically entail that we could, in turn, predict that event when looking forward.[10] Each case of serendipity arises because of epistemological limitations, but these limitations are part of the very nature of serendipity itself—serendipity occurs precisely when there is a failure to expect that a particular process will produce the valuable outcome it does. Thus, there are reasons to see serendipity as a case of strong emergence.

I do not have the space here to fully explore whether serendipity is a case of weak or strong emergence, but wish to highlight the role of epistemic expectations by raising the question. That is, there is an intimate interaction in instances of serendipitous discovery between epistemic expectations—about where knowledge might come from, or predictions about what will happen next—and the impact of retrospectively recognizing serendipity upon those expectations. Serendipity, in challenging such expectations, changes them.

3. Surprise and Epistemic Expectations

Thagard (2002) argues that surprise is an emotional input to the questioning process that makes abduction both possible and useful. We are led by our surprise to reason about possible explanations for anomalies, for example. An important aspect of the sagacity, or wisdom involved in serendipity is this perception of potential value, leading an observer to attend to an unexpected observation rather than simply dismissing it. As Fleming did with his moldy petri dish, we look more closely because something has surprised us and roused our curiosity. The surprise that accompanies serendipity is not always the sudden and shocking kind of surprise that we experience when a jack-in-the-box springs forth, however. In many cases, it is more of what some call an "aha-experience"—the psychological experience of having a new idea about how things connect, or seeing something in a new light, or with a new sense of appreciation. In all cases, however, the experience is of one's own expectations being overturned.

While surprise and other emotional or "aha" responses to a shift in our expectations operate on the level of the individual, the expectations themselves derive both from personal experience and, importantly, from the norms of our community. The relevant norms have to do with how knowledge is expected to be produced, or are about who is expected to produce or contribute knowledge, for example. Further, the role of expectations extends beyond creating the conditions for a moment of surprise. Serendipitous individuals encounter the unexpected, see it as potentially valuable, and thereby are open to sources of knowledge in the world that exceed their own expectations. They must also be willing to change those expectations, upon reflection. Because serendipity is more than cognitive, but also includes unexpected outcomes from the formation of new relationships or one's presence at certain times in certain places, the relevant expectations go further than those about what kinds of knowledge can be gained or even what methods might produce knowledge. New sources of knowledge can be unexpected results from experiments, but they can also be people from social or epistemic

[10] Nassim Taleb provides a similar approach to what he calls Black Swans—catastrophic events that came by surprise (2007). Taleb highlights the fact that although in retrospect we are often able to explain how Black Swan events occurred, cognitive biases prevent us from predicting their occurrence beforehand. However, even if we were perfectly aware of our cognitive biases, Black Swans would still occur.

communities, or new experiences, that were not previously thought to be potential sources of knowledge.

Cunha and colleagues introduce a concept useful here, the idea of “generative doubt” (Cunha et al. 2015). They analyse the case of Honda, a company often deemed serendipitous for its cornering of the North American market with their Super Cub motorcycles in the mid-1960s. The rapid rise to power of Honda in America has been explained by appeal to two separate narratives: in one, Honda is said to have planned well and accommodated new opportunities by being prepared; in the other, Honda is described as flexible and highly responsive to the changing circumstances as they unfolded. Cunha and colleagues suggest that a successful, serendipitous company moves between these strategic approaches via generative doubt. Generative doubt is, “the motivated search for understanding stimulated by the experience of not knowing” (Cunha et al. 2015, p. 13). As Cunha and colleagues demonstrate, this can be practiced on the community (organizational) level as well as by individuals.

In the case of Honda, the company indeed had a plan for marketing in the United States, but they were able to adapt to a new source of valuable information when it arose. Honda intended to directly compete with other popular manufacturers at the time, Yamaha and Harley Davidson, but were having a difficult time finding a place in that market. Then their salesmen in California reported that people were asking them a lot of questions about the Super Cub, the small and lightweight motorcycles they themselves were using, and Honda changed its overall strategy. They then had huge success with their new ad campaign slogan, “you meet the nicest people on a Honda,” opening a new market of motorcycle drivers. In the language of organizational management and as Cunha and colleagues interpret, Honda was able to use its centralized resources for manufacturing to adapt with a “bottom-up” strategy of taking up a suggestion from an unexpected source (Cunha et al. 2015).

The willingness to change expectations is something that can be learned. Chris Napolitano (2013) argues that, “intentional…serendipitous actions” lead to “serendipitous relations” in the life of an individual. These intentional actions include cultivating an open attitude to unexpected events as opportunities, and refining the skills needed to take advantage of such opportunities when they arise. As people do not always realize the value of an event at the time it occurs, but rather upon reflection and in light of its positive outcome, these skills are generalizable and adaptable, rather than specific reactions to certain kinds of events. Similarly, Estes notes that a scientist will not always be able to predict the trajectory of her own research career, as unexpected meetings, events and observations will change its direction over time. Thus, in order to maximize potentially serendipitous moments along the way, one’s expectations about the end result of one’s intentions must remain incomplete.

This involves not only preparedness, but also the intentional development of one’s *ability to adapt* to unexpected situations when they arise (Napolitano 2013, p. 312). As Napolitano suggests, “Simply recognizing an unusual event as being potentially gains-laden is not enough. An individual must seize the opportunities that they identify in that unexpected event” (2013, p. 304). Action must be taken to follow up on the insight that an unexpected event has potential value; the skills needed to take such action can be intentionally developed and honed. Both openness to one’s intentions leading to an unexpected outcome and the ability to adapt to and act upon opportunities for re-evaluating one’s own expectations about the outcome of a process are the types of skills relevant for serendipity.

There are skills involved in cultivating one’s ability to recognize potential value in the unexpected, as well. Fine and Deegan point to this when they suggest that being present for an event in cases of temporal serendipity is not likely to be random. Ethnographers, rather, have a sense about when a major cultural event is likely to take place and where: “Even though events are unpredictable, types of events tend to occur regularly at particular times…and we depend on this patterned quality of events to permit us to make temporal choices about when to observe” (Fine & Deegan 1996, p. 439). Those who manage to hone such skills are called “super-encounterers” by Sanda Erdelez. Erdelez (1997) studies “information encountering”—the “accidental discovery of useful or interesting information”—as a distinct aspect of human information behaviour (p. 412). The super-encounterers she interviewed not only feel their research benefits from frequent, accidental discoveries of information, but also see themselves as acting in ways that encourage such beneficial encounters: “they believed in *creating* situations conducive to encountering” (Erdelez 1997, p. 417, emphasis mine). Thus, individuals can develop skills that benefit them both before and after they encounter something unexpected, thereby actively enabling serendipitous discovery.

However, as in the case of the floppy-eared rabbits, conditions beyond the intentions or skills of the individual may act as a constraint on serendipitous discovery. Barber and Fox (1958) describe several factors that can interfere: limited laboratory resources (running out of rabbits), preconceptions about what kinds of discoveries are possible (assumptions about the nature of cartilage), a greater interest in an alternative research direction, and time constraints. Abigail McBirnie (2008) observes that the researchers and jazz musicians she interviews often recognize potential value in an unexpected encounter and yet fail to follow up on that recognition to make a discovery. This is due to what she calls “serendipity filters” or “pressures,” including “time, need, responsibility, and environment” (McBirnie 2008, p. 608). People susceptible to such filters may have a hard time turning toward the value they perceive because they feel they cannot turn away from the work they are already engaged with.

Lori McCay-Peet suggests there are both internal and external precipitating conditions that affect “an individual’s ability and inclination to become aware of, respond to, and follow up on a potentially serendipitous experience”—these conditions thereby “ultimately impact the outcome” (2011, p. 2). Conditions include the physical and social context in which the experience occurs, as well as the more general context in which the individual works and lives. The internal conditions McCay-Peet lists are, “misleading preconceptions,” “divergent behavior,” and “feelings of frustration” (2011, p. 3). While these are examples of individual actions and personal characteristics, they are also the kinds of actions and characteristics that are strongly influenced by external conditions such as community attitudes and institutional organization. Thus, individuals can and do manipulate conditions so that unexpected encounters with new information will more likely occur. Individuals can also exercise some control over whether they recognize and follow up on valuable, unexpected encounters. However, the efforts of individuals are also constrained by context.

So on the level of the individual, serendipity is often seen as paradoxical, requiring both luck and skill. McBirnie calls this the “paradox of control” (McBirnie 2008, p. 611). She argues that the process aspect of serendipity is beyond the control of the individual, highlighting that complex processes are often unpredictable. The perception of serendipity, and its results, however, are more susceptible to control: the skills involved in such perception and in one’s ability to be adaptive to changing circumstances can be developed. But, as just noted, the environment in which the individual is perceiving and acting may be such that her skills are constrained, and she cannot follow up despite recognizing the potential value in the unexpected. So one must be “lucky” not only in terms of encountering the unexpected, but also in terms of having the opportunity to put one’s skills to use and succeed in making a discovery.

The work the category of serendipity does is to differentiate such discoveries from the merely lucky; credit is due for the insight that accompanies surprise. Rachel McKinnon (2014) offers some insight into the relationship between luck and due credit, in her analysis of the phrase “you make your own luck.” McKinnon argues that while it is not technically possible to develop skills that directly increase the luck one experiences, it is possible to develop skills that keep one “in the game longer” and thereby increase the overall probability that one will be lucky. Super-encounterers and other serendipitous individuals seem to have the necessary skills to keep themselves in the game long enough to encounter the unexpected more often, to recognize its potential value and then to follow it up.

Again, beyond having the required skills and therefore deserving credit for their role in the discovery process, they must also be in the right time and place—in the right game—for the utilization of those skills to lead to success. Some have argued, for instance, that Fleming’s involvement in the discovery of penicillin has more to do with his role in the scientific community than with the actual insight he displayed in observing *P. notatum* in his petri dish.[11] He would not have played a role in the particular process that led to the valuable outcome, despite his observation, if he had not also been an active lab director and educator in the community at the time (Copeland 2015).[12] In the following section, I look at what kind of scientific community is more likely to encourage rather than constrain the efforts of individuals to play a role in a serendipitous discovery.

4. **Implications for the Norms and Practice of Science**

Some have argued that the democratization of knowledge production, through recent developments in communications technology for instance, increases the likelihood of serendipitous discovery. Increasingly diverse groups become involved in science and other intellectual enterprises, exposing each other to new sources of knowledge and new ways of knowing (eg: Andriani 2017). Others have argued that serendipity occurs most often when individual scientists have free reign to follow their research in any chosen direction (Bush 1945, p. 14; see also Bedessem & Ruphy).

In turn, some have argued that serendipity can be suppressed in a hierarchical system. Toby Sommer (2001) calls attention to this by coining the term “Bahramdipity”. Bahram is the Persian king in the fairy tale who attempts to foil the princes of Serendip’s efforts to reap the benefits of their wise observations. In science, Bahramdipity describes instances of failing to give credit to individuals who would have played a role in the discovery process. Sommer’s examples are of scientists whose potential discoveries are elided or neglected by those higher up in the hierarchy of the scientific community. One famous example is that of Selman Waksman and his graduate student Albert Schatz. Schatz claimed to have brought the importance of streptomycin as an antibiotic to Waksman’s attention and to have done much of the necessary work, but Waksman was credited with the discovery and received the Nobel

[11] Most notably, Fleming himself, who humbly declared during his Nobel Prize Award speech that, “My only merit is that I did not neglect the observation and that I pursued the subject as a bacteriologist” (Fleming 1945).
[12] I am far from alone in pointing out, for instance, that others had made similar observations but had lacked the timeliness and social connections that Fleming had. A fairly well-known example is the French graduate student Ernest Duchesne, whose dissertation reporting on the therapeutic effects of another *Penicillium* mold was submitted in 1897. Duchesne’s work remained unknown and he died a few years later, however, and so his preliminary efforts were not taken up to be part of the discovery process that ultimately led to penicillin (see Copeland 2015 for other examples).

Prize. A recent study also shows that bottom-up management of research in science leads to a greater number of serendipitous discoveries (Murayama et al. 2015). The suggestion, then, is that undirected, egalitarian communities of independent scientists are more likely to generate serendipitous discoveries than communities with leaders and specific goals.

However, this suggestion raises the following question: if each scientist works in isolation toward their own desired ends, how does science itself fare as a consequence? For one, contemporary science is complex, both in terms of theory and tools—how can any one scientist have the necessary knowledge and resources to achieve progress, without the help of others?[13] Also, if the goals of these individualized scientists are for personal profit, how can we ensure the practice of science generates knowledge valuable to society as a whole?

These questions have been taken up by an ongoing discussion in philosophy of science regarding the possible conflict between the priority rule in science—that the first scientists to complete a discovery process get all the credit for that discovery—and the imperative to share knowledge in the interest of scientific progress overall.[14] It seems that if a scientist or group seeks credit for a discovery, they have an interest in keeping their knowledge to themselves until the discovery process is complete. This, however, prevents other scientists (and society) from accessing the knowledge being produced by that process until the discovery is made. I argue that because this delay not only affects the time it may take for the discovery to be made, by decreasing the likelihood of cooperation, for example. It also affects the potential for serendipitous discovery. Consequently, there is an additional, personal reason for an individual scientist to want to share her knowledge, because it improves her chances overall of playing a role in the completion of a discovery process.

Recent work on this has been an effort to reconcile a scientist's personal desire for garnering credit for making a discovery with what Merton called the "communist norm" of science (Strevens forthcoming; Heesen forthcoming). Michael Strevens argues that the priority rule plays an important part in science as an incentive for individual scientists to work toward potentially valuable discoveries; they desire the prestige that making a discovery will grant them, and so through the work of individual, ambitious scientists, science benefits overall from their discoveries (Strevens 2003). Despite the role of competition between scientists and groups, however, both Strevens and Remco Heesen provide arguments for why it nevertheless benefits individual scientists to subscribe to a communist approach to science, or "total sharing" of information. I suggest that a similar argument can be made from serendipity.

To return to the features of serendipity described above, I have argued that it emerges, unpredicted, from the processes of scientific practice and communication. Thus, no one scientist can say ahead of time that she will play a role in a serendipitous discovery process, let alone in its completion. Epistemic expectations determine when serendipity will occur, by defining what counts as unexpected. Insofar as epistemic expectations are overturned by serendipity, the occurrence of serendipity (the reflection upon the unexpected significance of a source of knowledge, for instance) will alter the future expectations of individual scientists and potentially of the community of scientists as a whole.

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[13] Aspects of these first two questions are often discussed under the problem of the division of cognitive labour (see Kitcher 1990; Weisburg & Muldoon 2009, for examples).

[14] I would like to thank an anonymous reviewer for drawing my attention to the relevance of this discussion.

From the perspective of an individual scientist, she may be blind to the ultimate value of some of what she publishes.[15] A contribution she makes to science by publishing her intermediate results, for instance, may unexpectedly result in her involvement in another discovery process. On the other hand, some other scientist may publish his intermediate results and thereby unexpectedly contribute to a discovery process *she* will gain the prestige for having completed. The information produced along the way to one discovery, that is, may contribute to other research outcomes in ways not predicted by the scientists involved in that underlying discovery process, *serendipitously*.

The potential for the publication of intermediate results to benefit both science and the individual scientist has been argued for by Thomas Boyer (2014). He points to a distinction between community norms that allow an individual to benefit from the publication of intermediate results, and norms that do not. Specifically, in a community in which publishing the end result of a discovery process receives far more credit than publishing an intermediate result, the individual lacks incentive to publish early. Boyer suggests that, if a community wanted to encourage early publications, it could be better to "acknowledge the value of preliminary and intermediate steps, instead of emphasizing only the achievement of the last step (and keeping only "big names" for history's records)" (Boyer 2014, p. 27). If preliminary and intermediate steps were more widely acknowledged as being essential for serendipitous discovery, I suggest, they would have higher value. This goes hand in hand with widening the scope of credit due for enabling scientific discovery to include unexpected sources of valuable knowledge.

As an example, take the discussion concerning the role that Rosalind Franklin played in the discovery of the structure of DNA. As James Watson (2010) tells it in his autobiographical account, the process of this discovery was marked by serendipity, one instance of which was the happening upon Franklin's crystallographic images, which inspired Watson and Francis Crick to think in terms of a helix. A footnote in the original *Nature* publication of the model Watson and Crick came up with thanked Franklin for "stimulating" them with a "general knowledge" of her research results (Watson & Crick 1953, pp. 737-8). Thus, from one perspective, Watson's encounter with Franklin was fortunate happenstance, and he was lucky to have gained the knowledge he needed from an unexpected resource. From another perspective, Franklin contributed to the process of discovery as a fellow scientist. The perception of a discovery as serendipitous points to the recognition that it was enabled by something unexpected. When our expectations shift, however, for example from thinking Watson was wise in seeing the worth of Franklin's work to thinking Franklin was deserving of credit for her contribution to the discovery, our perception of the nature of the serendipity involved also shifts. Rather than being wise for recognizing the value of an accidental finding, Watson was fortunate to have made a particular social connection and to benefit from another's work. Since Watson's autobiographical account was published, it has become common to suggest that what led Watson to see his access to Franklin's research as serendipitous reflected a mistaken expectation about her ability (as a woman) to contribute to his scientific discovery process. Whether or not this interpretation is correct, it reflects a general belief that such expectations (should) have changed over time. [16]

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[15] As Strevens (forthcoming) points out, not only data is of value when it comes to sharing scientific knowledge. In keeping with the variations of serendipity I have described above, all sorts of information might have unexpected value, enabling a discovery by making it timely or by creating a social connection between scientists that leads to the exchange of further information, for example.

[16] A further factor in the discussion over Franklin's contribution to this discovery concerns whether Watson and Crick illegitimately gained access to Franklin's data. Michelle Gibbons offers insight into the relevance of that

Perhaps paradoxically, a scientific community whose members are more likely to take advantage of opportunities for serendipitous discovery is also more likely to recognize the control it can exercise over who (and what) is perceived as a possible source of new knowledge. Consider as a counterexample Kantorovich's "naturalistic" depiction of serendipity in science. The observation of an anomaly, reasoning about its potential value for scientific knowledge, and the acceptance of this observation as potentially valuable by the broader scientific community are, as Kantorovich (1993) argues, processes guided by epistemic norms. Scientists do not take the time to attend to an unusual observation nor do they take up such an observation into processes of investigation and inquiry unless they believe it has epistemic worth, and epistemic worth is determined according to the norms of scientific knowledge. But Kantorovich argues that this process operates fully at the group level, in the form of a "collective brain," and is therefore as unintentional as evolution itself (1993, p. 211). However, because the scientific community is made up of individual members, it is not the scientific community in the abstract but rather individual scientists whose actions and behaviour maintain (and sometimes change) the norms of their community.

As I suggested in the previous section, some control may be exercised over serendipity by the individual, insofar as she can cultivate the associated skills. Serendipity-related skills may also be cultivated by a community that, for instance, utilizes generative doubt, as Honda did in the example given by Cunha and colleagues and above. Generative doubt in relation to the norms of epistemic expectations would require an approach somewhat like the following: A scientific community that has developed appropriate epistemic norms about what kinds of methods and observations, for example, can be expected to produce scientific knowledge, may also be skilled in adapting those norms when surprising events call those expectations into question. In contrast to an organism that evolves through mutations and natural selection, then, a serendipitous scientific community is a group that can *intend to learn from their experience* with the unexpected. Further, such a community will be more adaptive to the broader needs of society: when problems arise, the cultivation of adaptive skills and the ability to take up the work of others quickly into a discovery process can result in more timely and effective responses to those problems (Michener et al. 2009).

In sum, a community that learns to expect the unexpected might also readily acknowledge the potential value of preliminary and intermediate results, *alongside* the value of competition and the priority rule. That is, serendipity does not exist without the underlying process, in relation to which its outcome is oblique. But the expectations that ground the intentions that drive that process, in a self-reflecting community, will themselves shift as the community learns about the limits of its own expectations. Therefore, serendipity will continue to be a relevant category for describing discoveries, insofar as what expected (and consequently, what is unexpected) is a shifting ground.[17] In a scientific community with serendipity-based norms, such as one that adopts generative doubt toward its own epistemic norms, individual scientists will continue to have the same chances of being serendipitously involved in the completion of a discovery process. In this way, awareness of the potential for serendipity results in a democratization of knowledge-production, by widening the scope of expectations about potential

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discussion for determining Franklin's role and offers a complementary approach to the discovery in her article, "Reassessing Discovery" (Gibbons 2012).

[17] One can assume there will always be unexpected observations or events, so long as scientists fall short of omniscience.

sources of knowledge, without also resulting in the wholesale individualization of the pursuit of discovery.

As a final point, I return to the problem of whether this kind of community encourages individuals to exercise the relevant skills and to play a role in serendipitous discovery. I argue that it does, in the same way that it improves the economy of research. That is, as Thagard (2002) points out, contexts in which experiments can be done without high costs to the overall research programme—requiring too much time, attention, or material resources—are conducive to serendipity. This may be, for example, because experiments can be done that initially seem unnecessary, or unimportant, but that can sometimes result in the accidental discovery of valuable knowledge. Such was the case in Patrick Lee's path to discovery of the potential value of the reovirus for cancer research: He allowed one of his graduate students to conduct an experiment that Lee assumed would reveal nothing interesting, but which had a surprising result. Further, because it was economical to repeat the experiment, hypotheses of error and coincidence could be ruled out to conclude that, indeed, an interesting anomalous result had been obtained (Thagard 2002, pp. 86-87).[18] Serendipity does not occur as a result of "blindly stumbling on important phenomena" or through simple trial and error, but rather during the course of normal scientific work (Thagard and Croft 1999, p. 128). The more scientific work that can be done, the more likely a discovery might occur—there is both an increase in opportunities for chance observations and an increased possibility that such observations will be followed up.

The early publication of results, as Boyer (2014) alludes, improves the economy of research by preventing the unnecessary repetition of discovery-related work. Likewise, a community in which knowledge is regularly shared decreases the burden on its individual members for doing that work by improving the chances they will (unexpectedly) come across results that are useful. It thereby also improves the chances that an individual scientist's efforts will result in a discovery, by making it more possible that her published results will be taken up by someone else. Individualized constraints such as pressures on time, resources and attention are thereby mitigated by one's role as a node in the greater network of science. In this way, scientists are kept "in the game" longer when they publish more (preliminary, intermediate) results of their research, and consequently there is a higher probability that the exercise of their skills will lead to them playing a role in a serendipitous discovery process.

5. Conclusion

This paper has sought to define serendipity as it exists in the practice of science, to delineate its key features, and to illustrate how taking serendipity seriously grounds specific normative frameworks and approaches to publication practices. I have argued that serendipity is an emergent property of scientific discoveries, describing an oblique relationship between the outcome of a discovery process and the intentions that drove it forward. Further, the conditions that generate one instance of serendipity are also thereby changed by it.

[18] Howard Gest points to a similar factor in his recounting of serendipity in the isolation of the vitamin C molecule—the fact that one group of scientists had a much faster and less costly test available to them allowed for their belated, yet successful involvement in that discovery process (Gest 1997, p. 23).

Serendipity is often conceived of as a “flash of insight” or a “eureka” moment, triggered by an unexpected observation or event. I have shown that, particularly in the context of scientific practice and scientific discovery, serendipity can be complex. A serendipitous discovery process may involve several unexpected observations and events, and may entail the formation of a network of interactions between individuals from various communities, backgrounds and even times. Therefore, serendipity in science is better seen as a process that occurs within (and sometimes beyond) the scientific community, if we are to understand how it emerges from scientific practice.

I argue that the most important aspect of serendipity is its role in disrupting and changing epistemic expectations, in particular about the kinds of discoveries that might be made and where they may originate. Science has specific epistemic norms about the methods and types of observations likely to produce knowledge. Further, scientists have expectations about who might have the knowledge they need. When a discovery is retrospectively categorized as serendipitous, it is because somewhere along the process of that discovery an unexpected event, observation or source of knowledge led to an unimagined outcome.

Because individuals and even communities can cultivate skills that allow them both to perceive the potential value in the unexpected more readily and to adapt and act to follow up on that value, serendipity can, to a degree, be controlled. This is paradoxical on the individual level, insofar as the individual cannot control the rest of serendipity. Rather, environmental and even internalized constraints that reflect the norms and resources of their community and context can prevent individuals from utilizing the skills they have. Thus, serendipity requires both luck and skill.

It is not paradoxical when we look to the level of the scientific community, as the space in which serendipitous processes of discovery occur. That is, some community norms and practices can circumvent the paradox through mitigation. For instance, communities that share information readily not only create opportunities for unexpected discoveries to occur. Sharing information also improves the economy of research overall, meaning that more scientists can share the work to be done on any particular discovery process. Consequently, opportunities for utilizing the relevant skills of perception and adaptation will both be more frequent and more effective from the perspective of individuals.

In conclusion, if we acknowledge both the prevalence and importance of serendipity to the practice of science, and want to encourage it, more needs to be done than ensuring different kinds of scientists casually meet up at the lab water cooler. The role of epistemic expectations needs to be taken seriously, and each member of the scientific community ought to participate both in exposing the limitations of those expectations and by contributing knowledge to the broader network. While further recommendations could be made, I have here argued that at least one aspect of a scientific community, the regular sharing of knowledge so that it can be taken up by other scientists, will encourage serendipitous discovery.

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