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SERENDIPITY IN THE SCIENCES – EXPLORING THE BOUNDARIES

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ABSTRACT

Serendipity in the sciences is an unexpected experience prompted by valuable interaction with ideas, information, objects, or phenomena. While serendipity is often associated with the "aha" and "eureka" moments that characterize well-known scientific discoveries such as the structure of DNA, serendipity may be more accurately described as a factor across the various stages of the scientific process. For example, serendipity in the sciences includes those unexpected encounters with prior research findings that are fostered by informal knowledge sharing within and among scientific communities. Serendipity's contribution to science is increasingly noted by scientists in formal scientific reports, by funding agencies which recognize the need to make room and provide support for serendipity in science, and is often credited with the development of fruitful scientific careers. This paper describes the process of serendipity—the pattern of the phenomenon—that will be familiar to many who have experienced it and noteworthy for those whose have not. Through examples of serendipity in the sciences, different perspectives on its role are explored and lessons drawn.

INTRODUCTION

> *The history of discovery is full of such arrivals at unexpected destinations, and arrivals at the right destination by the wrong boat.*
>
> ~Arthur Koestler, 1964, p. 145

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Serendipity, a combination of "chance, sagacity and a valued outcome" (Copeland 2015, p. 17), is an integral part of the scientific process of discovery. In a scientometric study of 205 *Citation Classics*, commentaries by the authors of highly cited scientific papers, Campanario (1996) found 17 (8.3 per cent) of the commentaries reported chance or luck was involved in the research process, though just one to two percent of the citations actually use the term "serendipity" (McBirnie & Urquhart 2011). Campanario classified the appearance of serendipity in these commentaries, based on Van Andel's (1994) conceptualization of serendipity and reflective of journalist Arthur Koestler's (1964) musings on discovery and arrivals, quoted above:

1. The goal of a research project is reached accidentally;
2. In the course of an investigation, something is discovered that does not have to do with the original research (Campanario, 1996, p. 10).

The distinction between two "types" of serendipity is arbitrary, divided only by the nature of its perceived unexpectedness; regardless of whether a case falls roughly into the first or second category, a serendipitous experience must contain an element of accident, chance, or luck. For example, it may be that the intended research goal is reached by chance, in an unexpected or unplanned manner or, rather than reaching the intended goal, something else entirely is accomplished and ascribed to luck. The sagacity and valued outcome of serendipity that Copeland (2015) refers to in her definition is assumed in both types of serendipity. Luck on its own is never enough, as "chance favors only the prepared mind" (Louis Pasteur, as quoted in Liestman 1992, p. 530). Moreover, other factors, including characteristics of the environment, are key to serendipitous experiences (McCay-Peet, Toms, & Kelloway 2015).

Much of what is associated with serendipity in the sciences is closely coupled with discoveries that have global implications. Simonton (2004) lists a number of "episodes of serendipity" in science and technology dating from 1492 to 1948, including Fleming's discovery of penicillin, Röntgen's discovery of X Rays, and de Maestral's invention of Velcro. Gaugh (2010), in a beautifully illustrated book, describes such episodes up to 2005, when the Spirit Rover found evidence of liquid water on Mars, a monumental discovery for humankind. However, as Copeland (2015) notes in her exploration of serendipity in clinical research, "While serendipity is commonly associated with discoveries of greater-than-average value, this is not a necessary element of serendipity" (p. 5). Moreover, there are many examples of serendipity in science that are not about the "arrival" *per se* (i.e., the scientific discovery). In many cases, the serendipitous experiences speak to the scientific process, the incremental and unexpected steps taken that help scientists build knowledge and lead them in new directions in their research and profession. While "aha" or "eureka" moments are typically associated with the "discoveries of greater-than-average" in the sciences (e.g., Watson and Crick's discovery of the structure of DNA [Watson & Crick 1953, Watson 1968]), many more serendipitous experiences have a wide variety of positive implications, though lack the same level of prestige.

In this paper, we first introduce the phenomenon of serendipity, its origin, definition, and evolving standing in the sciences. We describe the process of serendipity as it has been modelled as an information-centric phenomenon, reliant on triggers or cues (verbal, visual, or textual) that convey information which spark the experience. We in turn explain how this model of the serendipitous experience extends to the sciences. We then take a look at serendipity from a variety of perspectives relating to two of its less discussed potential triggers, namely verbal and textual triggers, as well as the notion of career serendipity as it relates to the professional lives of scientists. Throughout, we provide examples of serendipitous experiences, drawing out potential lessons to be learned by scientists in all fields and those who support their endeavors.

BACKGROUND

Horace Walpole, an English man of letters, coined the term *serendipity* in 1754 when he referenced a Persian fairy tale, *The Three Princes of Serendip*, in a letter to his friend, Horace Mann. Walpole explained, "as their Highnesses travelled, they were always making discoveries, by accidents and sagacity, of things which they were not in quest of" (Walpole 1754, as quoted in Merton and Barber 2004, p. 2). Because of its association with seeking, finding, and discovery, the term serendipity was particularly well suited to be picked up by both collectors and scientists when an edited volume of Walpole's letters, including the one referenced above, was first published in

1833 (Merton & Barber 2004). However, while the use of the term serendipity became popular among bibliophiles and antiquarians in the Western World in the Victoria era, it was much slower to catch on among practising scientists. Though the Victorians were well aware of the role of accidents in scientific research and discovery, it was not until the 1940s or 1950s that scientists began to use the term serendipity (Merton & Barber 2004). Merton (1948), a sociologist, noted serendipity's relation to Charles Saunders Peirce's concept of abduction in science–the construction of creative explanations for observations or the notice of a "surprising fact" that leads to the development of a hypothesis. The abductive experience has been described as if being "jerked from our perceptual and conceptual slumber with a surprise" (Merrell 2005, p. 93).

One of the impediments to the term serendipity's adoption by the scientific community has been its negative connotation, attributable to its association with luck, accident, and error (Díaz de Chumaceiro 1997). In the nineteenth century, the Reverend William Whewell, an historian of science, demonstrated this reservation when he wrote:

> *No scientific discovery* can, with any justice, be considered *due to accident*….The common love of the marvelous and the vulgar desire to bring down the greatest achievements of genius to our own level, may lead men to ascribe such results to any casual circumstances which accompany them; but no one who fairly considers the real nature of great discoveries, and the intellectual processes which they involve, can seriously hold the opinion of there being the effect of accident….*Such accidents never happen to common men* (Whewell 1847, as quoted in Merton and Barber 2004, pp. 43-44).

Whewell could not reconcile serendipity's association with science because he equated scientific discovery with genius and serendipity with accident. The latter, Whewell maintained, diminishes the intellectual process involved in scientific discovery. An anonymous critic of Whewell at the time, however, argued that accidents have indisputably sparked scientific discovery (e.g., polarization by Huygen [Simonton 2004]), but while anyone may be able to make an observation, only those with "the most distinguished talents" (p. 43) could follow it through to make an advance in science (Merton & Barber 2004). These talents may be what Walpole had in mind when he first paired *accident* with *sagacity* in his description of serendipity in his letter to Horace Mann in the earliest mention of "serendipity."

Barber and Fox (1958) provide an example of this pairing—accident and sagacity—in their case study of the work of two scientists. Barber and Fox noted that the two scientists observed the same phenomenon: the injection of rabbits with a plant protease caused rabbit's ears to flop. However, only one of the scientists, Lewis Thomas, recognized the significance of the unexplained phenomenon and followed through, ultimately making a scientific discovery relating to rheumatic fever; "serendipity gained" for Thomas, "serendipity lost" for the other scientist, Aaron Kellner. Barber and Fox first learned of the serendipitous circumstances around the discovery relating to the floppy-eared rabbits in an article in the *Times*. No mention is made of serendipity in Thomas's (1956) report of the discovery in a prominent peer-reviewed journal although he does hint at it: "*For reasons not relevant to the present discussion* rabbits were injected intravenously with a solution of crude papain" (p. 245, emphasis added). Though history suggests a "scarce appreciation" of the role of serendipity in science (Campanario 1996), a review of recent biomedical research indicates that the tide may be turning; scientists commonly report serendipitous experiences in relation to their research (Allen, Erdelez, & Marinov 2013). Rather than simply noted by those with established careers and sound reputations in the scientific community (Díaz de Chumaceiro 1997), scientists now may be more comfortable attributing aspects of their research success to serendipity.

Despite the reluctance at times to attribute some scientific discoveries, at least in part, to serendipity, the phenomenon can undeniably have huge economic, medical, social, and political implications. Unsurprisingly, the motivation among scientists, institutions, and funding agencies to tip the scales toward "serendipity gained" is significant and how this can be achieved is both a topic of discussion in the media and the science community and, increasingly, a focus of research. The following section examines serendipity as a process influenced by a variety of factors. Individual differences, environment, work culture, research funding, technology, and other factors all play a potentially important role and, in many ways, provide a road map for facilitating serendipity in the sciences.

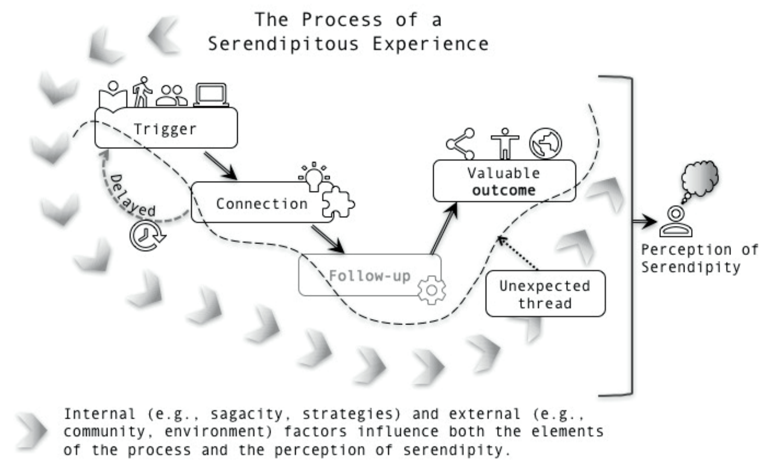

Fig 1 The Process of a Serendipitous Experience (adapted from McCay-Peet & Toms, 2015).

THE PROCESS OF A SERENDIPITOUS EXPERIENCE

McBirnie and Urquhart (2011) wrote: "Although sometimes described as a sudden moment of recognition, the clichéd flash of inspiration, serendipity is, upon closer inspection, both longitudinal and cumulative, the result of multiple events occurring over time" (n.p.). Due to serendipity's information-centric quality and an increasing interest in the phenomenon, a number of models of the process of serendipity have been developed through information science research. Fig 1 illustrates the process of a serendipitous experience (adapted from McCay-Peet & Toms 2015) based on a study of a range of knowledge workers' (e.g., journalist, historian, molecular biologist) experiences of serendipity and prior research and models of serendipity and related constructs (e.g., Cunha 2005, Erdelez 2005, Makri & Blandford 2012, McCay-Peet & Toms 2015, Rubin, Burkell, & Quan-Haase 2011, Sun, Sharples, & Makri 2011).

The model illustrates a serendipitous experience largely starting with a *trigger*. In a scientific context, a trigger, a verbal, visual, or textual cue, may be noticed, for example, while reading the literature, having a conversation with colleagues, conducting an experiment, while outside observing nature, or running a web search. A *connection* may be made immediately, or may be delayed, between the trigger and one's knowledge and experience. For example, in an interview with a molecular biologist who described a serendipitous experience, the biologist noted making a connection between her knowledge of insects which contain antifreeze proteins and the insects she saw x-ray in front of her, hopping in the snow, while she was out skiing during her leisure time (McCay-Peet & Toms 2015). Similarly, there was the connection made by Watson and Crick when they saw the x-ray crystallographic results of a sample of DNA in Rosalind Franklin's laboratory and deduced the alpha-helix nature of DNA, solving its structure and starting a revolution in the fields of biology and genetics (Watson 1968). *Follow-up* involves the work needed to make the most of the trigger-connection, to bring the serendipitous experience to fruition, to achieve that *valuable outcome* which may be felt at personal, organizational or community, and global levels. For example, Thomas followed up with experiments relating to the floppy eared rabbits, while Kellner did not (Barber & Fox 1958); the DNA example speaks for itself. The valuable outcome may be new and fruitful connections to scientists studying a similar phenomenon, a new career direction, or a scientific discovery (e.g., Thomas's discovery relating to rheumatic fever [Barber & Fox 1958]), or an important new area of research. An *unexpected thread* runs through one or more elements of this process with, for example, a surprising connection or unforeseen valuable outcome. The process of a serendipitous experience may be influenced by the interaction of both internal (e.g., sagacity, personality, personal strategies) and external factors (e.g., interaction with colleagues, design of a physical or digital space), reflecting "the concept of duality at [serendipity's] core" (McBirnie & Urquhart 2011, n.p.), a duality that research is just beginning to examine by exploring internal and external influences (Björneborn 2008, McCay-Peet, Toms, & Kelloway 2015).

Many have noted the importance of internal factors with respect to serendipity, as shown in the preceding discussion of sagacity and the prepared mind. *Super-encounterers*, for example, are people who are convinced of the importance of information encountering, "a memorable experience of an unexpected discovery of useful or interesting information" (Erdelez 1999, p. 25) and they frequently encounter information in this manner. Simonton (2004) pointed out that some scientists appear luckier than others, suggesting that some are, perhaps, more adept at exploiting their chance encounters, i.e., illustrating the sagacity component of the serendipitous experience as well as the value of developing strategies to increase opportunities for serendipity. Copeland (2016), however, underlines the importance of “community-based serendipity” in contrast to individualistic serendipity; that is, the involvement of a community of scientists in a serendipitous experience (e.g., communication among colleagues; colleagues’ participation in experiments and peer review; further research; or the application of a discovery).

Bell Labs is touted as the United States’ “gold standard for innovation” not only because of what was invented in its research and development laboratory (e.g., transistor, silicon solar cell, cellular telephone system) but because it was specifically designed to support serendipity (Corneliussen 2013). Jon Gertner, a former Bell Labs executive, credited the innovativeness of the Lab to its architecture; the buildings were interconnected, encouraging employees from different departments to interact with one another (Corneliussen 2013). Designing buildings to support serendipitous encounters and a dynamic work culture is one way to spur innovation and discovery (e.g., IBM, Canadian Institute for Advanced Research), but others (e.g., Jackson 2012) also note the importance of financial support for basic, curiosity-driven research such as that conducted at Bell Labs. Furthermore, in relation to environmental factors, technology has also come to the fore in discussions around serendipity in the past couple of decades. A growing body of research now examines how to develop digital information environments, such as digital libraries and social media, that support the serendipitous process to facilitate unexpected encounters with information that otherwise may not have been found (e.g., McCay-Peet, Toms & Kelloway 2015).

EXPLORING THE BOUNDARIES OF SERENDIPITY

While a common process is discernable across many different examples of serendipity (McCay-Peet & Toms 2015), there is still potential for variety within that process and many perspectives on serendipity have been offered that are relevant to today’s active scientific community. While three triggers of a serendipitous experience have been noted (verbal, textual, visual) (McCay-Peet & Toms 2015), experiences triggered by visual cues, namely observations of unexpected phenomena by scientists, (e.g., alpha-helix nature of DNA [Watson 1968]), appear to resonate in practice and in the literature (e.g., Gaughan 2010, Roberts 1989, Simonton 2004) more so than those more closely associated with encountering information in an article or talking with a colleague.

To draw attention to the two triggers or catalysts of serendipitous experiences that are less evident in current discussions of serendipity in the sciences, but clearly significant, we focus now on serendipitous experiences marked by:

1) verbal or, more accurately, *social* triggers (e.g., a scientist's discussion with a colleague); and
2) *textual* triggers (e.g., a scientist's interaction with a passage in a digital or paper-based source).

Finally, we discuss career serendipity, unexpected and valuable experiences that have a profound influence on the direction and output of the careers of scientists. The two triggers of serendipitous experiences that we explore (social and textual) and career serendipity are not mutually exclusive, and others surely exist. We focus on these to explore a range of experiences within the boundaries of serendipity in the sciences and to draw lessons from them.

SOCIAL

As noted earlier, while serendipity is often associated with the lone scientist's "eureka" moment, the serendipitous process may be fostered by a community rather than solely by an individual. Copeland (2015, 2016) underlines the importance of scientific communities, or interactive networks of scientists, in serendipity and argues that some communities are more likely to experience serendipity than others due to their features, namely:

> encouraging members to take advantage of unexpected opportunities; enabling members to give and receive support for their insights while engaging in epistemic cooperation; and making new and accepted knowledge readily available to all members of the community. Further, community values and norms determine which unexpected observations will be taken up into processes of discovery (Copeland 2015, p. 177).

While social interaction is not necessarily required for serendipity to occur, an analysis of 50 randomly selected narratives drawn from the Citation Classics Database indicate that *collaboration* and *exchange*, involving an interaction between a scientist and other people (e.g., a colleague) were common motifs or recurring themes in serendipity-related narratives (McBirnie & Urquhart 2011). Exchange, in fact, was the most common motif of the four identified (exchange, solo, collaboration, chain), further underlining the importance of the social aspect of serendipity, as the exchange motif involved interaction between the scientist (the narrator) and another person. The exchange motif underscores the point made by Copeland (2016): individual contributions relative to serendipitous experiences are vital (e.g., observation, recognition of value, follow-up) but the scientific community provides the conditions necessary to support these serendipitous experiences (e.g., exchange of knowledge).

Barber and Fox (1958), for example, note that in the case of floppy eared rabbits, “As so often happens in science, an unsolved puzzle was kept in mind [by Thomas] for eventual solution through informal exchanges between scientists, rather than through the formal medium of published communications” (p. 132). Pepys (2007) recounted an experience of serendipity in which he was waiting to be granted entry to a chemical company when he struck up a conversation with a fellow visitor whom he did not know, Dr. Don Renn. In conversation, Pepys shared a scientific observation that had recently baffled him. Renn, as it turned out, was just the person he needed to talk to. Renn was an expert on the polygalactan polysaccharide, a complex carbohydrate produced by seaweed, and was able to provide both the information and materials that led Pepys and his team to make a breakthrough and led to “the original suggestion that this could be a novel therapeutic approach to systemic and local forms of amyloidosis [a rare disease]” (p. 568).

It seems that, to foster serendipity, scientists may need to “put themselves out there,” to be social. A medical doctor noted, in McCay-Peet and Toms’ (2015) study of serendipity among knowledge workers:

> Potentially if things are really on the boil, and you are really in a dynamic environment with people who have lots of views and lots of ideas and things are happening and they have big social networks etc., etc., then things [. . .] do often happen (p. 1471).

The willingness to give and attend seminars, and to share ideas and unexpected observations through informal exchanges with colleagues and people both inside and outside your field is a compellingly important condition for facilitating serendipity, generating new ideas and perspectives essential for novel approaches and discoveries in science. One of us (Wells) experienced this on numerous occasions while working as a young marine scientist at a large oceanographic institute in Halifax (Wells 2016).

Another example of the social side of serendipity comes from a description of scientific interactions at the famous Marine Biological Laboratory (MBL) of Woods Hole, Massachusetts. As described by Lewis Thomas in his book, *The Lives of a Cell* (Thomas 1974), the highly influential yet autonomous MBL was known for attracting "successive generations of people in bunches" (p. 69). Thomas describes one of the "governing mechanisms" of the MBL—interactions among the scientists, for example, at the Friday evening lecture in which international guest speakers presented and discussed their findings and at the local beach where biologists and even the occasional physicist would talk and draw diagrams in the sand. From such spontaneous sharing of information, many new ideas and approaches would often emerge in a very unpredictable and serendipitous manner: "Not many institutions can produce this spontaneous music at will, summer after summer, year after year" (Thomas 1974, p. 74). The publication record of scientists working at the MBL speaks for itself, especially through its main journal, The *Biological Bulletin*.

TEXTUAL

Although there are opportunities for exchange among scientists within their communities, it may be the scientist interacting with digital or paper-based sources of information that triggers serendipitous experiences. The *solo* and *chain* motifs identified by McBirnie and Urquhart (2011) through their analysis of the serendipity-related narratives in the Citation Classics Database highlight interactions between scientists and information or objects rather than among scientists as in the exchange and collaboration motifs. While finding something unexpected in the physical "stacks" in a traditional library is still very tightly coupled with humanities scholars (see for example, Martin & Quan-Haase 2013), stumbling upon digital information has become an important avenue of serendipity (Quan-Haase, Martin, & McCay-Peet 2015) and the same is true for scientists. As Workman *et al*. (2016) note, a walk among the library stacks or a search in PubMed may lead to encounters with information that address a prior though pressing information need. In a digital context, *serendipitous information retrieval* occurs when people are searching or browsing, "meandering from topic to topic while concurrently recognizing interesting and informative information en route" (Toms 2000, n.p.).

Due to very rapid advances in technology since the 1980s (e.g., personal computers, the web, social media, smartphones) and hyperlinking capabilities in general, digital environments provide a particularly fertile ground for *connections*, a vital part of the serendipitous process (see Fig 1) (McCay-Peet, Toms, & Kelloway 2015). Swanson (1986), an information scientist, first illustrated the value of what has become known as "linking" in the context of "literature-based discovery" when he found a connection between two independent bodies of literature on dietary fish oil and Raynaud's syndrome, the narrowing of arteries that supply blood to the skin. Swanson found, through a search of the Medline and Embase databases, that there was a logical connection between the two and thus posited that dietary fish oil could help treat Raynaud's syndrome (later supported by research). This has since spawned research on "undiscovered public knowledge" and the development of tools to support literature-based discovery and knowledge-based discovery in general. In this line, Workman *et al*. (2016), found that "serendipitous knowledge discovery" in online environments:

1) is an iterative process;
2) often involves reformulation;
3) is grounded in prior knowledge; and
4) is reliant on the way in which information is organized and presented.

Based on those principles, Workman *et al*. created a web-based tool called "Spark," designed to help scientists develop new hypotheses and discover connections within existing scientific information and knowledge. It remains to be seen, however, whether removing some of the chance by using such a tool has the potential to reduce the likelihood that any discoveries made through this approach would be perceived as serendipitous (McBirnie 2008, McCay-Peet & Toms 2015). McCay-Peet and Toms (2015) argue that in addition to being trigger-rich, highlighting triggers and enabling connections, an environment that supports serendipitous experiences must also be perceived to lead to the unexpected.

The technological challenge of support for serendipity, in the sciences and beyond, is the balance that needs to be struck between giving individuals content that matches their knowledge and experience, but also challenging them with content that perhaps may have the power to change their thinking from the norm. Perhaps this is particularly true for connections that are more difficult to make, connections that require a higher degree of intellectual capacity, knowledge, or experience on the part of the individual (McCay-Peet & Toms 2015). Famed novelist and philosopher Umberto Eco (1998) referred to people's knowledge and previous experience as our "background books." These background books are our "preconceived notions of the world, derived from our cultural tradition" (Eco 1998, p. 54) through which we interpret and explain what we encounter in the world. The interaction between our observations and our "background books" has an impact on the mental connections that we make. While our background books may help us to see beyond the information given (Bruner 1973), our background books may also prevent us from seeing, thinking about, or accepting something new.

The challenge with knowledge- and literature-based discovery is not only discovering what is there, but recognizing that not everything that is known is there to begin with. Many studies, especially ones with negative results, never make it to primary publication due to the difficulty of identifying possible "instructive failures" and the greater likelihood that successful research will be accepted for publication (Barber & Fox 1958, p. 131). Recall that Thomas kept the unsolved problem of the floppy eared rabbits in the back of his mind, ready for a possible solution to surface through informal communication with colleagues, not relying on formal scientific dissemination channels (Barber & Fox 1958). There is also a wealth of knowledge in the extensive grey literature (e.g., government technical reports), much of which until recently was not digitized and hence was difficult to access and explore comprehensively.

Because few failures or puzzling observations make it to publication, reducing the potential of text-based triggers of serendipitous experiences, talking with colleagues through informal exchanges is particularly important, as indicated in the preceding section of the social aspects of serendipity. Some also have pointed out the need to teach students the importance of sharing their observations, both informally and formally. Lenox (1985) stated that students of science are taught traditional scientific methods (e.g., ask questions, develop hypotheses, develop or adopt methods, collect data, test hypotheses) but omits "*how scientists arrive at the first step of the process*" (p. 282), which is posing important and testable questions. Lenox describes three methods by which scientists are drawn to particular problems:

1) the building-up method;
2) insight; and
3) chance or serendipitous discovery.

Lenox argues that, as serendipity is an important phenomenon in the sciences, undergraduate students should be informed about it so that they will be both open to chance observations and (possibly) recognize their potential significance. Lenox, for example, underlined the importance of *observing* over *seeing* and developing the habit of accurately recording both expected and unexpected observations. Moreover, he stressed the importance of teaching *students* to report the "actual process of discovery" (p. 284) to the scientific community, including incidents of chance that affects their work. Further, Nutefall and Ryder (2010) identify three strategies for preparing for serendipity that may benefit all students, science students among them: "the development of a rhetorical disposition towards sources, a sense of the rhetorical relationships among sources in a field, and strategies for accumulating background knowledge" (p. 232). As a result, scientists may be more apt to enable an opportunity for serendipitous discovery or insights with other scientists, by sharing personal observations more fully and make it more likely that they themselves will make connections between what they know and what they have found serendipitously through their readings and direct experiences. The example of the Marine Biological Laboratory, described earlier, should be kept in mind.

CAREER SERENDIPITY

Pepys (2007), Wells (2008) and more recently Estes (2016) have recounted how serendipitous experiences have shaped their careers, leading them to new areas of research, providing opportunities for career progression, and making important professional connections. As McCay-Peet and Toms (2015) note, in the case of career serendipity, the valuable outcomes associated with serendipitous experiences are largely personal in nature but can have a "cascading impact" on their organizations, fields of research, and beyond. Betsworth and Hansen (1996), in a study of 237 older adults associated with a university in the United States, found that 59 per cent of survey respondents believed their careers were influenced by serendipity. An analysis of reported incidents resulted in the development of 11 categories of serendipity-related career development events, including, for example: *professional or personal connections*; *unexpected advancement*; *right place/right time*; *encouragement of others*; *influence of previous work/volunteer experiences*; *obstacles in original career path*; and *unexpected exposure to interest area* (p. 95).

One of us, Wells (2008), as another example, described the impact of serendipity on his career, characterized by a combination of professional connections and encouragement from others. From an early tip about an available job; to being at sea and making unexpected observations of surface pollution, which piqued an interest in aquatic toxicology; to be working at a biological station that just happened to have an expert on the topic who was heading to a university and was recruiting graduate students; chance occurrences played a major role in the direction and early success of his career (Wells 2008). An important point, however, is that each unexpected opportunity requires a decision, involves a risk of failure, and seems open-ended at the time. But there is no doubt that the unexpected, the phenomenon of serendipity, plays a role in a person's career path if one is alert to opportunity and willing to cope with at least temporary uncertainty. Both characteristics (being opportunistic and confident) bode well for a person interested in conducting discovery science in a chosen field.

Exposure to a variety of chance events clearly can have a significant and positive impact on an individual's career (Bright, Pryor, & Harpham 2005). Because of the potentially numerous valuable outcomes that may arise in relation to career development, Bright *et al*. urge career counselors to encourage students to volunteer, join clubs, and generally increase the variety and extent of their interactions with others. Career serendipity is thus tightly coupled with the social aspect of the phenomenon of serendipity. However, this advice, which essentially encourages social behavior, could be equally valuable to those at various stages of a career. Career adaptability has become an important skill in an insecure work world, one which "waxes and wanes" regarding opportunities, and rewards those who face uncertainty with optimism and a desire to seize the moment when it appears, often unexpectedly. As Wells (2013) stated, "we cannot easily predict where and when the next major breakthrough [in science] will occur" (p. 208), and the same is true for associated careers.

CONCLUSION

The profound impact of some scientific discoveries aided by serendipity (e.g., penicillin, DNA, lasers, water on Mars) on society cannot be overstated, hence our general interest in the topic. This paper, however, explored the phenomenon of serendipity in the sciences, moving outside the traditional narrative of the serendipitous "discoveries of greater-than-average value" (Copeland, 2015, p. 5) to examine serendipity beyond this boundary, sharing examples which illustrate reliance on interactions with other people or the scientific literature and those that do not necessarily relate directly to discoveries at all (e.g., career serendipity). The importance of this phenomenon to both science and the progress of society in general has been recently highlighted by Nassim Nicholas Taleb (2010) in The Black Swan, which explores "the impact of the highly improbable" (the book's subtitle). That serendipity, as a process in discovery, is alive and well and highly influential is beyond doubt. Conditions and factors that contribute to the process of serendipitous experiences in the sciences include the exchange of information among established scientists, both formally and informally, and the education of early career scientists about serendipity. It is hoped that the latter group will be ready to fully exploit the phenomenon of serendipity in their research and careers, and expand our understanding of its boundaries and contributions to science.

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