Abstract

Serendipity captures the interaction between a skilled human agent and a fortuitous event in the environment. Although it features in many stories of invention and discovery, its antecedents remain elusive. This paper combines research from different domains of psychology to present a model of the cognitive processes required for a serendipitous episode to occur. The model describes a prepared mind that consists of an informational state and an attentional state. Both states are continually updating. An accident is considered as a trigger event that updates both of these and feeds information back into the prepared mind. If the accident is noticed, a cycle of judgement and amplification occurs, eventually leading to an output. The model generates novel predictions that point to an increased understanding of how best to scaffold serendipitous moments.

Accidental Thinking: The Serendipitous Cognition Model

In his speech on winning the Nobel prize 1945 for the discovery of penicillin, which he shared with Howard Florey and Boris Chain, Alexander Fleming said:

> We all know that chance, fortune, fate or destiny – call it what you will has played a considerable part in many of the great discoveries in science. We do not know how many, for all scientists who have hit on something new have not disclosed exactly how it happened. We do know, though, that in many cases it was a chance observation which took them into a track which eventually led to a real advance in knowledge or practice. This is especially true of the biological sciences for there we are dealing with living mechanisms about which there are enormous gaps in our knowledge.

This points to a core notion in folk psychology: the idea that a lack of knowledge or skills can be rectified by luck. However, attributing moments of innovation simply to chance discovery is problematic in terms of intentionality (Weisberg, 2015) and epistemic credit (Kieran, 2017; Sand, 2020). Therefore, the most common framework to understand this combination is that of serendipity. Serendipity refers to the coming together of accident and sagacity. It is a word (famously coined by Walpole in 1754) that aims to describe those moments when the right thing happens to the right person, and through this combination, new knowledge and understanding are generated. Although it is "slippery", most definitions converge on three important aspects: an unforeseen event, the wisdom to make the most of that event, and a happy outcome – what Busch describes as surprise, agency and value (Busch, 2022).

Despite its unplanned nature, this mixture of personal skill and good fortune plays a major role in many tales of innovation and discovery across multiple levels, from the personal to the historic (Campanario, 1996; Gaillard & Moonen, 2023; Thagard, 2012). It is, therefore, something that is implicitly encouraged, particularly because it appears to be behind many breakthrough moments in scientific creativity and commercial innovation (Baumeister et al., 2010; Busch, 2022; Makri et al., 2014; Roberts, 1989; Ross & Copeland, 2022; Yaqub, 2018). However, how serendipity occurs on a personal level is still unclear.

This lack of clarity regarding its precipitating causes frustrates attempts to increase its prevalence. This paper presents a model of the cognitive mechanisms from perception to decision making that underlie serendipity. The Serendipitous Cognition Model (SCM; Figure 1) details the interlinked processes and the necessary conditions for noticing contingent and relational material affordances (Björneborn, 2017; Chemero, 2003) alongside the skills required to exploit them. It incorporates existing research paradigms from different psychological domains and suggests novel hypotheses and research areas, specifically drawing on interactions between the skills of the human agent and the affordances of accidents in the environment.

Although closely related to both chance and luck (and on the other hand, calamity and disaster[1]), serendipity represents a different category of engagement with unplanned and unpredicted events. For the purposes of this paper, I follow Griffith in defining chance as the continual flow of environmental fluctuations (Griffith, 2010) which are not internal to the agent and over which the agent has no conscious or subconscious control. Although it should be acknowledged that chance can also happen as a result of stochastic internal associations, the model outlined in this paper will focus on those associations that combine internal processes and external events. A definition such as this may be narrower, but it will allow a deeper engagement with this highly complex phenomenon. However, the environment is in a constant state of chancey flux and so another qualifier is needed: Meaningfulness. Once the moment of chance becomes meaningful to a person, it becomes either luck or serendipity (Rescher, 1995). Luck describes those things which happen that are beyond the control of the agent, but which cause a material change in her environment: “something happens to a person, it is not something that he does” and can be positive or negative in valence (Griffith,

[1] I thank Simon Penny for this observation.

2010, p. 46). This lack of valence and the uncontrollable nature of the event lies behind the phrases “dumb” or “blind” luck. The metaphors used here point to the muting of traditional agentic senses. In contrast, serendipity requires the active involvement of the human agent to make the most of the opportunities afforded by unanticipated changes in the environment, traditionally with a positive outcome (Arfini et al., 2018; Sauer & Copeland, 2021) although the nature of that outcome is liable to change over time.

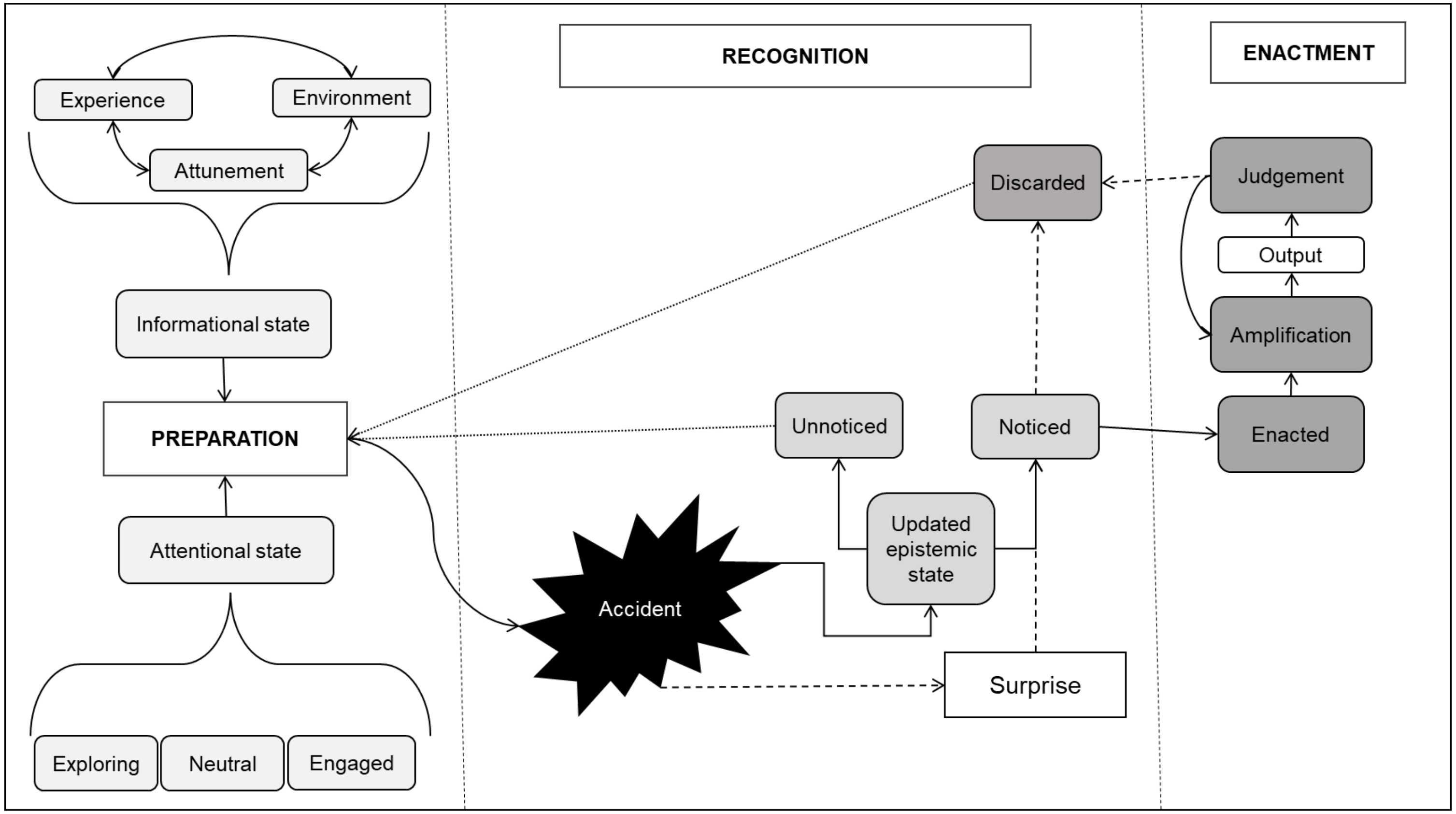
This active involvement of a human agent makes it open to psychological analysis. However, to date, the role of serendipity has been neglected in the psychological literature (although see Bandura’s APA presidential address; Bandura, 1982), particularly in theories of cognition (although see Arfini et al., 2018, for an important exception). This is perhaps because its emergent and messy nature requires a shift away from the individual and internal cognitive processes that are traditionally associated with this discipline (Malafouris, 2023). However, the underlying processes of noticing and extracting useful information from the environment, processing it, and monitoring the outcome have recognisable cognitive correlates. While the foundations of cognitive psychology draw from a tradition of methodological solipsism which isolates the thinker from their environment (Fodor, 1980), there is an increase in perspectives drawing on theories that see the environment as part of the cognitive system rather than a distraction from it. In this respect, these frameworks that see cognition as an *interaction* between thinker (or tinkerer) and world seem particularly apposite for understanding the emergent process of serendipity. Therefore, although cognitive in nature, the model laid out in this paper is not internalist and rather views cognition as a process that extends beyond the individual agent.

There are related perspectives on the ways in which cognition can extend “beyond the brain”. Each lays an emphasis on different aspects of extension into the environment and, importantly, offer different perspectives on the role of the human agent. However, for the purpose of the argument laid out here, I shall draw on similarities across these theoretical positions while acknowledging the differences. Overall, these frameworks cast cognition as an interactive and systemic process (Vallée-Tourangeau & Vallée-Tourangeau, 2020) in which transient cognitive systems are softly formed, that is they coalesce in support of a goal before disengaging and reforming (Kimmel & Hristova, 2021; Kirsh, 2009). These systems are soft formed because they can break up and reform as the goal state changes rather than being fixed. The SCM draws on frameworks from this tradition to clarify how the relationship between world and mind that underlies a serendipitous episode can be understood. Casting serendipity as a cognitive process, that is, an information generating and knowledge producing activity, will expand our understanding both of serendipity and the ways in which the relationship between mind and world is manifested through action. It will also allow a framework for models of extended and distributed cognition to investigate the important role of the unplanned and unintended in cognitive processes (Copeland et al., 2023; Feiten et al., 2023; Gallagher, 2022).

However, such a perspective requires us to move away from current methods of assessing serendipity, which tend to rely in the main on self-report, either through interviews (Makri et al., 2014; McCay-Peet & Toms, 2015), blog posts (Rubin et al., 2011), collection of stories or case studies (Van Andel, 1994; Yaqub, 2018). These reports of serendipitous moments are complicated by two factors: survivorship bias, and individual differences in the tendency to label something as serendipitous. In other words, a model which can inspire experimental prospective research to analyse serendipity in the moment is needed to complement the theories of serendipity that are based on retrospective analysis of either the serendipitous agent or the others (Ross & Vallée-Tourangeau, 2021b). The proposed SCM aims to provide the framework for this investigation.

Figure 1

The Serendipitous Cognition Model



The Serendipitous Cognition Model

The SCM relies heavily on an understanding of thinking as reliant on more than internal mechanisms. It emphasizes the emergent properties of material engagement and the dynamics of human and material entanglement as transient states relying on soft-formed cognitive assemblies rather than innate properties of either. For this reason, each of the three phases of the SCM – preparation, recognition, and enactment – is seen as extended into the environment.

Preparation: The Underlying System State

Louis Pasteur (1854) famously suggested that "Dans les champs de l'observation, le hasard ne favorise que les ésprits preparés", commonly translated as "chance favours a prepared mind". While this is only a footnote in a much longer talk rather than an empirically motivated claim, its hold on the popular imagination and its combination of preparation and chance is a useful hook to begin to unpick the phenomenon of serendipity. Indeed, this 'prepared' mind stance has characterized much of the research into serendipity to date, especially that which sees serendipity as a capability or mindset (Busch, 2020; de Rond, 2014).

However, while there have been some levels of success in understanding trait dispositions to experiencing serendipity, the research literature is inconclusive. McCay Peet and Toms (2015) found that openness to experience and locus of control had no relationship with how often people reported serendipity in a digital environment, although there was a weak relationship with extraversion. Looking at incidental information acquisition, a close relation to serendipity (Erdelez & Makri, 2020), Heinström (2006) found similar results– there was an unambiguous relationship between extraversion and incidental information acquisition but again no relationship with the theoretically plausible factor of openness to experience. Despite this, Heinström did find a significant relationship between emotional state and information encountering. In a controlled experiment of search behaviours in an online shopping experience, Grange et al. (2019) found that tolerance of risk was positively associated with perceived serendipity, as was the type of search behaviour of the shoppers, both in terms of the depth of product choice and depth of review sampling. This emphasis on typical behaviours echoes the second facet of Björneborn's (2017) theory of the key personal factors required for serendipity – curiosity, mobility and sensitivity. The model outlined here adds a different perspective to trait research founded on the position that all minds are situated in an ongoing sensemaking process. In this light, the prepared mind emerges from a felicitous arrangement of agent and environment (Glăveanu, 2022); a prepared and extended cognitive *state* rather than an underlying trait. In other words, the prepared mind reflects precisely the sort of transient extended cognitive system suggested above, formed with a specific task goal which assumes the surrounding environment is an equal agent in that system. Crucially, this system is not stable because it consists of two fluid yet central aspects: the knowledge state (which is continually updating and accumulating content) and the attentional state (which is in state of change).

SCM posits that the knowledge state of the cognitive system at any time is determined by three factors – experience, attunement and the surrounding environment. There is an emphasis in SCM on the temporal situatedness of the cognitive system, that is, it is influenced by what has come before and also anticipates what is to come (Arfini et al., 2018). As Solomon (2016) reports, the elements that contribute to serendipity may occur at different points in time with different temporal interludes. Serendipity arises from the conscious awareness of the difference between what has been predicted (based on prior experience) and is theoretically plausible and what occurs (Yaqub, 2018). This often happens at a subconscious level but in serendipity it reaches a threshold of consciousness (Munnich & Ranney, 2018). To understand what happens in these extended moments, we can draw on the literature on incubation (Gilhooly, 2019; Sio & Ormerod, 2009), which refers to a period of non-goal-directed work on a problem prior to the gathered information being put to use. For example, in problem-solving, incubation refers to a moment between the problem presentation and the solution being generated that is, importantly, marked by a lack of activity.

However, the iterative nature of the SCM points to an incubation process that is less sharply delineated than currently theorised. The two aspects of experience and anticipation are dynamically interactive – experiences drive anticipation and anticipation is needed to make sense of the experiences (Rummel & Kvavilashvili, 2022). In other words, SCM is explicit about rejecting a blank slate, linear model of cognition that moves from a state of ignorance via a time of incubation to one of knowledge. Instead, SCM posits an iterative and incremental process in which the act of noticing is determined by what has come before as well as the characteristics of what is currently there *and* what is anticipated. These lead to an incubation process that is multi-layered and iterative, one which extends over time and is determined by experience as well as anticipation. The knowledge state of the cognitive system is not simply reliant on an abstracted reflection but changes through experience of the world, both by leading to conceptual change and by the building of environments which support certain forms of cognitive activity. For this reason, the SCM contains a loop back to preparation, when accidents have shifted the epistemic landscape slightly but not yet enough to yield a change in the system's trajectory. In other words, the SCM does not posit an "all or nothing" approach to the informational state of the system, but rather assumes that different aspects of memory and environment are assigned different weights over time. This means that the period of incubation is also the period of preparation: the two are collapsed.

The collapse of incubation and preparation in SCM is predicated on three types of memory traces or indices: failure, success, and incompleteness or unexplained phenomena. These cognitive indices or markers are what Seifert et al (1994, p. 87) call “special memory traces”, and are akin to a form of retrieval cues. These traces draw on theories that posit that recognition of items in the environment is not an all or nothing phenomenon (an agent knows she has seen the item before or she does not) but instead works on underlying strengths of association (an agent does not recognise an item but still has some underlying memory of its source characteristics; Fox & Osth, 2022). Similarly, the notion of memory flags is an explanation for the Zeigarnik effect (Zeigarnik, 1927), which suggests that memory for unfinished tasks is greater than for completed tasks. The SCM draws from these theories and suggests a task could be unfinished for three reasons: failure, incomplete understanding, and unexploited success. Being unfinished then lays down a weighted memory trace, the cumulative effects of which add strength to an association.

The most commonly explored of these memory markers are ones elicited by failure. The importance of failure for learning is becoming a robust finding across the learning sciences (Jackson et al., 2022) and has been documented as an important part of the scientific process (Barwich, 2019; Firestein, 2016). From the perspective of the SCM, failure leads to enhanced recognition of the utility of external hints. Research looking at the role of accidents in cognition commonly suggests experience is likely to generate failure indices (Seifert et al., 1994), which will make the person more ready to notice and interpret felicitous cues (Suzuki & Abe, 2001). Seifert et al (1994) asked students to answer questions before giving them a seemingly unrelated lexical decision task where the answers to the questions were hidden as primes. Students were invited to return a day later to answer a mixture of new and old questions. Old questions that were both failed and primed were answered more successfully.

According to Seifert et al, these indices lay down markers for future reference at a sub-personal level.

The two other types of trace are less empirically evidenced but are also plausible. Indices of incompleteness are related to failure, but they indicate the failure to complete a series of investigations satisfactorily rather than a cessation due to failure. That is, they encompass events that are noticed and registered as being potentially useful but are not yet ready for follow-up. When Jocelyn Bell Burnett first noticed the anomalous pattern that would lead to the discovery of pulsars, she did not immediately follow it up but consciously labelled it as potentially useful. Similarly, Csikszentmihalyi (1996) tells the story of Vera Rubin's discovery of the galaxy rotation problem, which came when she was playing with overlapping pictures. The overlap was "blind" and unintentional, but the recognition of the importance came from many years' attunement to typical patterns that allowed her to identify non-typical ones.

A success index refers to a felicitous event which happens without recognition and so is not followed up but still registers a low-level strength of association. For example, in an early observation of serendipity in problem solving, Steffensen et al., (2016) described a participant solving a problem which required them to discover how to place an odd number of animals in an even number of pens so that there is an even number in each pen. Solution is only possible if two of the pens overlap. The participant realised the need for an overlap after fiddling with the representations of the pens, generating a felicitous overlap which led to the problem solution. However, crucially, a similar moment that happened less than ten minutes previously was not consciously noticed. At that stage, the participant did not notice the accident, but the SCM would hypothesise that their epistemic landscape had changed, and this may have allowed them to be more able to recognise the helpful accident later. The SCM's predictions that unexpected and theoretically implausible events need to be experienced more than once to shift the weighting of theoretical plausibility may explain the lack of a reliable effect of hints (or clues pointing to a solution) on problem solving under a short time span when hints are only presented once (Ormerod et al., 2002; Ross & Vallée-Tourangeau, 2022).

Success and incompleteness indices would reflect what Yaqub (2018) calls Stephanian serendipity after Paula Stephan. This form of serendipity suggests that exploration and accidents can lead to intriguing observations that only become useful at later moments. Yaqub cites Benedictus dropping a glass flask which had held a solution of collodion (cellulose nitrate, prepared from cotton and nitric acid) and which lined the inside. The flask did not break, and it was only afterwards when he heard about car accidents that Benedictus realised the potential value of shatter resistant glass. These two types of indices, therefore, function as markers of an interesting idea whose value has yet to come. These indices do not need to be long lasting, but they are often longer lasting than we see in laboratory studies. For example, Shaw (2022) demonstrated that hints from the environment are incorporated beyond the normal period associated with laboratory experiments when participants have a longer time to solve a problem.

Importantly, these indices are not always held by the agent "in her head" but are rather better conceived of as being distributed across internal and external stores. For example, Makri et al. (2014)'s study of serendipity strategies suggests that digital environments can be designed to support offloading of interesting information which is not directly relevant at the moment of encounter but may be useful later. This reflects another aspect of the knowledge state of the overall cognitive system: The environment. This environment should facilitate both the storing and easy access of these indices of failure and success. Artists' studios often function in this way as repositories for initial ideas or abandoned projects and so generate an immersive archive (Sjöholm, 2014). Thus, incubation becomes an extended state.

In addition, the SCM holds that a prepared mind is one which is situated in an environment which easily facilitates the generation of many different unplanned accidents (Björneborn, 2017). Austin (2003) introduces the idea of the Kettering Principle - those minds which are constantly on the move are more likely to encounter new ideas. Combinatorial theories such as this have marked many approaches to creativity and, indeed, Thagard (2012) argues that there is overwhelming support for the combinatorial conjecture in most examples of scientific innovation. In the cognitive domain, conceptual synthesis is a key part of Finke et al.'s (1992) approach to creative cognition – GENEPLORE - in which initial musings are combined to generate new ideas. For these theorists, these combinations are conceived of as internal cogitations. However, these combinations do not have to be merely conceptual but can take concrete forms – Watson’s understanding of the structure of the double helix, for example, came from the combination of cardboard representations of nucleobases (Watson & Stent, 1998). Indeed, there is some evidence that working with external representations like this can improve creative outcomes. Shimizu & Okada (2021) gave participants objects to play with to create a new toy in a combinatorial task and found that outcomes were rated more creative than when they were only given the objects to look at or were asked to imagine those components.

Simonton (2010, 2023) makes the case for a level of blindness in these combinations, that is, ideas having an uncertain fit prior to trying them out. In other words, a combinatorial approach is not about knowing in advance which ideas go together but varying the ideas until they come together, without a guarantee of success. Under a framework of extended cognition, this blind variation (Campbell, 1960; selective retention is addressed below) is facilitated by an environment which afford these combinations of external as well as internal representations (Simonton, 2022). If something is unknown in advance, the cognitive load of combinatorial play to reveal the answer is reduced when the cognitive activity associated with generating combinations can be offloaded to the environment. For example, when Kirsh (2014) gave his participants a digital interface that allowed easy letter shuffling, it facilitated greater success in a word production task than the same task in an environment where moving letters carried a greater cost (Ross & Vallée-Tourangeau, 2021a). Thus, there is an interaction between individual skill and environmental affordances.

Finally, preparation is a matter of acquiring attunement to the surrounding domain and environment. It is a robust finding that expertise shifts perceptions across many domains (see Gobet, 2015 for a review). In addition, not only perception shifts with expertise; expertise or attunement to the environment informs different ways of moving and interacting with material that can facilitate the generation of accidental events (Ormerod & Gross, 2023). Attunement, therefore, is a form of skill that refers to the link between experience and the environment and emerges from the relationship between the two. Attunement to the domain reflects Yaqub's (2018) observation that serendipity must arise from a theoretically anomalous occurrence. To understand what is theoretically anomalous, the noticer must be steeped in an understanding of the theoretical domain. This is not simply an abstract understanding. Knowing what is unexpected underlies much expertise in artistic and creative domains. Although related to ideas of practical wisdom or tacit understanding, Copeland (2022) reminds us of the notion of metis which can be summarised as "cunning wisdom" and which she tells us is all about responsiveness to a situation rather than a set of fixed "knowledge". Understanding the nature of this form of attunement could tell us much about contemporary approaches to wisdom.

Therefore, the knowledge state that underpins SCM consists of three things: experience, environment, and attunement. This is a nonlinear view of serendipity; the things which happen over the course of the serendipitous incident not only feed forward into the outcome but also feed backwards in a recursive loop where a failure is a temporary state that leads to learning and change. Note that these three aspects of the prepared mind should not be understood as separate – experience and attunement are clearly interrelated but so are environment shifts, which come with attunement and experience. Attunement often means understanding what parts of the material world to move in order to better understand the environment. The moves in the environment are the basis for the changing experience state. Thus, the SCM suggests that we can only understand serendipity if we accept the mind as situated in an ongoing dynamic of change, both in relation to its own underpinnings and also the ongoing flux of the environment.

Direction of Attentional Focus

As well as having ongoing foundational knowledge, the cognitive agent is in an attentional state. This state changes on a shorter timescale than the knowledge state and can lead to differences in noticing or making sense of the surrounding environments. Given that serendipity is reliant on an attunement to, and relationship with, the environment, changes in attentional engagement may explain why there is a contingency in serendipitous moments even if the preparedness of the agent remains stable. In short, the attentional state interacts with the informational state to predict how likely an accident is to be noticed. Crucially, there are different ways that attention can be directed, which the model above suggests makes it more or less likely to pick up on external events. For ease, SCM addresses each of these attentional states separately, but it is likely that, rather than an abrupt switch from one form of attention to another, the transition between each state is more fluid and an agent may be in more than one state at the same time.

Engaged Attentional State

When it comes to the process of creative cognition, hyper-focused or flow states are characterized by a full and uninterrupted connection between the human agent and the material with which they are working, and the attentional field is narrowed (Ashinoff & Abu-Akel, 2021). This engaged flow state is an extreme one where the cognitive activity of interest consumes attention rather than a more routine state where habitual actions take over and attention is reduced, such as the flow state of driving the same route home (Christensen et al., 2016).

It is unclear whether this fully engaged state can generate serendipity, although it can, of course, generate accidents. For serendipity to arise in a such a state, the flow must be disrupted, and the human agent must become aware of a disconnect between themselves and the material world, and so the accident in this case needs to be disruptive enough to disrupt the flow state. The phenomenon of attentional blink (Raymond et al., 1992) demonstrates that, even when information is task relevant, it is likely to be overlooked in moments of significant attentional engagement. This could explain why experts report fewer moments of conscious serendipity. For example, as musicians become more skilled in improvisation they are able to respond to accidents in a non-conscious manner and so errors take on a different form during the performance (Lock & Sikk, 2022). It remains to be seen if expertise can be understood as an accumulation of multi-layered indices which quickly draw attention to the felicitous mistake.

This is adaptive behaviour; the conscious noticing and enacting of accidents is cognitively costly because it involves a change in the underlying cognitive trajectory. The actions being taken in this state progress the agent smoothly towards their goal. According to theories of problem solving (most notably PRODIGI; Ormerod et al., under review) if an individual appears to be making sufficient progress, then they may be reluctant to adopt strategies that require additional cognitive resources. This is even more likely when the accident may involve a hint to change goal state. So even if the intrusion is noticed, it may be actively disregarded (see enacting chance, below). Therefore, the model predicts that, when the agent is in a flow state and experiencing success, the nature of the accident will need to be more intrusive and more obviously felicitous.

Exploring Attentional State

Arfini (2023) suggests that the cognitive state most likely to precede serendipity is one of "aching ignorance", that is, one where the agent knows that she does not have full knowledge but wishes to attain it. The aching here indicates a state which is not necessarily unpleasant. For example, research on the state of impasse – or being stuck – suggests that such a state can be either positive or negatively valenced and desire to resolve uncertainty can be a positive moment (Ross & Arfini, 2024). The SCM predicts that this explorative state arises at two different but related points: First, when an agent is aware of her shortcomings and has exhausted the search space for solutions and so is more likely to be actively searching for external hints to scaffold her performance; and, second, when she is in a *curious* state. In other words, this state can be elicited by two different motivations - either by the internal desire to engage with the environment or the external constraint of failure of internal cogitation. Either way, attentional focus is on the surroundings.

There is a growing body of research which demonstrates the importance of failure and frustration to noticing felicitous environmental cues. Early failure may be important to generate a state of impasse which drives the agent to switch course (Ormerod & MacGregor, 2017) and make the mind more receptive to incidental information (Moss et al., 2011). For example, Ormerod et al. (2002) found that individuals did not make use of solution-relevant hints in solving insight problems until they had exhausted moves that appeared to make progress towards the problem goal. When it comes to models of problem solving, this phase echoes the phase of impasse (Arfini & Ross, 2023; Ross & Arfini, 2024), which is when the problem solver has come to a halt and cannot make any immediate progress. SCM predicts, therefore, that serendipity results from frustration and uncertainty, and accidents triggered during speculative epistemic foraging (that is manipulating the environment in such a way as to reveal new information) are more likely to be noticed, leading to the moment of serendipity.

Attention towards the environment does not always come from a frustrated state but can also be directed by intrinsic motivation to explore driven by curiosity (Gottlieb et al., 2013). However, such a state is still linked to the state of frustration because the actions on the world are epistemic rather than pragmatic (Kirsh, 2009). In other words, actions in this state are not directed towards a pragmatic goal in the way they are in the engaged state but are open-ended, which leads to a wider attentional field. The not-knowing in this case is a state that drives exploration and epistemic foraging. The nature of the accident is also determined by the anticipatory field of the agent, which is in turn informed by preparation phase.

Serendipitous accidents are epistemically relevant, that is, they change the knowledge state of the system, but they are not actively sought in their own right. Acknowledging the role of the environment in this way extends research on cognition, which has tended to present an agent-centric view, with the environment always being effectively recruited in support of the completion of a cognitive task (Bruineberg & Fabry, 2022). The SCM suggests that this directed and purposeful use of the environment in pursuit of a single goal would be less likely to generate noticed accidents than when the environment is recruited in a nonpurposeful manner because it is goal-directed, which makes the unintended less likely to be noticed.

Neutral Attentional State

For some researchers, a pure notion of serendipity must consist of things "which we were not in search of" to reflect Walpole's initial definition. It is certainly true that, when Walpole coined the phrase, he was not thinking about goal directed problem-solving. This reading of serendipity implies a neutral mind (Van Andel, 1994) not oriented towards a particular problem but one in which problem and solution are generated simultaneously. This definition of serendipity has led other researchers to generate categories such as "pseudoserendipity" to define moments where the serendipitous moment occurred in the process of research or goal-directed action (Roberts, 1989). It is perhaps unfortunate that the word "pseudo" implies a lesser status, and so this nomenclature has not gained traction. Other researchers argue that it is not always easy to define the difference between the two proposed forms of serendipity. For example, Simonton (2022, p. 306) argues that "a precise line cannot be drawn between the two serendipities" and Arfini et al. (2018) go so far as to call the distinction useless, echoing arguments from Copeland (2019) that often the serendipitous discovery can be as much about a process as a final outcome. From the perspective of SCM, there is no hierarchy between these proposed different forms of serendipity. However, the cyclical nature of the model and the increased weighting to accidental triggers proposed by the posited memory indices suggest that the informational state of the system would be more primed to recognise an accident which fits with prior experience. However, SCM does not rule out that there can be a combination of attuned informational state and non-attuned attentional state. This unfocussed attentional state is seen as a neutrally directed state. Whereas an engaged attentional state is focused on the task at hand, the neutral attentional state does not have a goal and rather is collecting information.

The weighting aspect of SCM suggests that in this attentional state where the agent is not sensitised to the information that could be generated by an accident, then the accident will need to be more sharply epistemically informative and more generally disruptive to be noticed. It has been robustly evidenced from prior studies is that, frequently, people *fail* to notice and take advantage of felicitous environmental events (Ormerod, 2023; Ross & Vallée-Tourangeau, 2022). The phenomenon of inattentional blindness demonstrates how even large changes in the environment can be missed. The most famous example of this is, perhaps, Simons and Chabris' (1999) research showing that, when participants were asked to watch a basketball game and count the number of passes, they failed to notice a person in a gorilla suit walking through the game. However, the majority of the experimental paradigms for exploring inattentional blindness draw on the presentation of unexpected stimuli which are not functional for the task at hand (Redlich et al., 2021). For example, noticing the gorilla in the middle of the basketball players would not support in any way the primary task of counting the passes. There is, therefore, an adaptive function to this form of attention conservation. Nonetheless, even in situations where the unexpected stimuli would support the completion of the primary task, such as in problem solving, research has shown that solution-relevant hints can be similarly ignored (Ormerod et al., 2002). Therefore, with a neutral attentional and informational state, SCM predicts the accident is less likely to be noticed.

The Accident

Dretske (2010) outlines two forms of causes that can help us understand the importance of the accident – structuring causes and triggering causes. What sets serendipity apart is that the triggering cause is an accident that arises from outside the cognitive system described in the preparation phase. Other aspects of serendipity, such as the need for domain-specific expertise or the role of other people and systemic structures, sustain *all* forms of discovery and innovation and so cannot be used to define serendipity as separate from these other related phenomena. A reviewer suggested that, for some examples of serendipity, the discovery itself can create the domain and the expertise and in the case of domain altering serendipity this is likely to happen. However, while the creation of a domain of expertise may define these stronger moments of serendipity, more often serendipity is reported within a system (Baumeister et al., 2010; Campanario, 1996; Thagard, 2012). Even more, it is reported that a discovery is not enacted because of frustrations with the surrounding system. For example, Boris Pavlovich Belousov's discovery of the foundations of the Belousov-Zhabotinsky Oscillator (Winfree, 1984) was followed up by the scientist but lay unpublished because it was not at that time considered possible – it failed to find sympathetic reviewers and was rejected from scientific discourse until after his death. So, while SCM does not dismiss this wider impact of serendipitous discovery for definition purposes, it remains the case that it is primarily the accident which defines whether a discovery be considered serendipitous or not.

Elsewhere, I have defended three characteristics of the serendipitous accident (Ross, 2022b). Originally, I suggested that the accident arises from either object-actions (that is pure "accident" in the folk understanding) or non-directed actions on and/or with objects. The SCM is less stringent about where the accident comes from and accepts accidental encounters with others as well as with objects and, indeed, would allow for the accidents to be the internal juxtaposition of thoughts. Second, while unintended, the results of the accident are noticed. Third, it represents a change in the cognitive trajectory and occasions the forming of a novel system with a different intention. If the last two criteria are not fulfilled, the accident is unnoticed and is likely only marked by indices of failure, success, or incompleteness of varying strengths.

There is some evidence that an accident is more likely to be noticed when it is actively generated by the agent's actions rather than presented without agential involvement. For example, Neth and Payne (2011) compared the performance of participants in a coin addition task. The factorial design compared performance in four conditions on coin solutions: when moving the coins themselves and being given a random array, when not moving and given a random array, when moving and given the array of a previous successful participant, and when not moving and given a successful array. The helpful array is the equivalent of the lucky break. The environment is arranged in such a way as to support and scaffold the problem solver without her doing anything. However, participants made fewer errors when they were allowed to interact with an unhelpful array than when they were given a static and already sorted and helpful array, suggesting that the actions themselves may be important to fully leverage the advantages of the presented array. Ross and Vallée-Tourangeau (2021a) observed similar results and noted that accidents were more effective when they were generated through intended but non-goal directed actions rather than being presented to the participants. In this case, they contrasted being able to move lettered tokens with being able to shuffle them in a word production task. SCM predicts therefore that serendipity is most likely to arise in action but an action which is not specifically goal directed although still intentional.

The Act of Noticing

In their model of serendipity, Rubin et al. (2011) suggest there are three key facets in preparation for a serendipitous moment – a prepared mind, a chance event and the act of noticing. The act of noticing is essential for serendipity to occur. The world may offer up several invitations and successful hints but as outlined above, these hints are often not used by agents to progress. Similarly, the world may offer up felicitous arrangements that are then used by the human agent but without a conscious noticing of the lucky moment. The SCM aligns itself with other models (Erdelez & Makri, 2020; Jiang et al., 2019; Rubin et al., 2011) to suggest that the act of noticing is an essential ingredient to combine both the accident and the prepared mind. Of course, it is dependent on each of these aspects as well. The more disruptive an accident is, the more likely it is to be noticed. Equally, the more attuned an agent is to environmental affordances, the more likely an accident is to be noticed. Noticing here is not necessarily marked by the "eureka" phenomenology but suggests that the agent changes from initial course.

In the research underlying their model, Rubin at al. (2011) noted that for most of the participants, this act of noticing was marked by surprise. Surprise has been theorised to be a metacognitive signal that updates mental models to incorporate new, unexpected information (Munnich & Ranney, 2018). At the affective level, surprise is accompanied by reliable phenomenological markers that can be positively or negatively valanced. As a basic human emotion (Ekman, 1992), surprise is universally recognisable, though inherently relational and idiosyncratic. More fundamentally, surprise marks the recognition that there was something that was not planned for or predicted but which elicits a feeling of truthiness. Expressing surprise is not the same as expressing scepticism; we are surprised by something which is evidentially true but which we have not considered before. This is clearly illustrated when we say "That would surprise me if it *were* true", where the level of surprise is related to the truth of the object (Ross & Webb, 2023).

The feeling of surprise may also be linked to the playful curiosity driving the exploring attentional state described above; surprise as a feeling is an important component of what motivates an individual to explore the world and knowledge space. As Clarke (2018, p. 521) suggests: "We humans often seem to actively seek out surprising events, deliberately harvesting novel and exciting streams of sensory stimulation." This perspective points to our role in generating it through epistemic ‘foraging’. In this way, rather than casting the human as a passive recipient of the surprising moment, surprise can be seen as part of a process of the flow of actions and events.

Enacting Chance

Serendipity involves reacting to the accident and, crucially, switching the trajectory in some way. Chance may direct action but, if this is done without conscious noticing, it is nothing more than the constitutional flow of being in the world. There is a real risk of definitional bloat if we define serendipity as reacting to anything unexpected in the world. At any one moment, human agents are constantly being directed through environments in flux. For example, all work with material requires adaptation to unexpected differences and changes in the material as part of the nature of the process but not all work with material can be seen as serendipitous (Glăveanu et al., 2013; March & Vallée-Tourangeau, 2022). The embracing of uncertainty which marks creative action (Ross, 2022a) may be a crucial part of preparation but something generating greater disruption is needed for serendipity.

At other times the accident can be noticed but not enacted. Erdelez (2004) reports exactly this in her experiment on information encountering. Participants were presented with a list of information relevant to the experimental task and embedded in this was a randomly assigned piece of information which related to their class assignment. Despite noticing this, they did not follow it up, presumably because they were constrained by the exigencies of the primary activity, the “game” of the experiment. Similarly, in a classic paper Barber and Fox (1958) described how two scientists make the same observation about the reaction of rabbit ears when injected with palpain but only one followed it up because of funding and time constraints. The second observation that did not exploit the interesting accident may well have generated an index of success and, indeed, clearly generated a strong enough memory of the incident to report it to the authors of the paper, but the surrounding structures were not in place to allow the enacting of this observation. Again, this points to the importance of understanding cognition as a process of sensemaking structured and supported by the surrounding environment.

Serendipity involves using the disruption to direct future action. Once noticed, the agent can take two courses of action: actively disregard the event or change course to fully exploit the opportunity. It is this latter than yields the "game changing" behaviour which marks a serendipitous event (Arfini et al., 2018). In addition, because the findings of the accident are necessarily unexpected, they require verification to accept that the illumination is valid starting the cycle of amplification and judgement.

The Cycle of Amplification and Judgement

Classical psychological perspectives on creative thinking tend to focus on the moment of ideation or illumination. However, within serendipitous cognition, the accident is epistemically opaque. That is, its accidental nature means that it does not inspire immediate trust, although it is self-evidentially worthy of consideration. This nature of the accident means that verification becomes an essential part of serendipity. This part of the model posits a cycle of amplification and judgement rather than a final and fixed end point. It is important to note that this cycle can operate on several levels from the personal to the social and extend across several time points and is often distributed across people as well as things. Take, for example, the discovery of penicillin. The initial observation was made by Fleming but, before he checked that he was right, he invited his assistant to come and look. The initial act of verification was immediately shared. The same was true of Jocelyn Bell who, after making the observation that explained the anomalies in her data, verified her initial findings along with her supervisor at the time. As pointed out by Lawley & Tompkins (2008), the act of amplifying the effects of a serendipitous accident is a skill in itself is one that is currently overlooked. What is particularly interesting about this skill is that it may be one that is separate from the noticing of the accident.

This cycle shows several overlaps with a classic Test-Operate-Test-Exit cycle (TOTE; Miller, 1960), that is, a cyclical structure of perception, performance, assessment of the results of the performance, and further performance. This cycle is dynamic; the act of running through these phases changes the world because they are rehearsed in that world, those changes then inform the assessment of the next stage of the cycle. It aligns with the argument threaded throughout the SCM that the environment, cognition, and action cannot be disentangled. However, the cycle of verification does not have a true exit function; rather, the verification continues and, if it is discarded, it feeds back to update the informational state through experience. If an output is created, once in the world, the serendipitous discovery is amplified and judged by others.

From a cognitive perspective, this phase draws heavily on metacognitive mechanisms. Broadly put, metacognition refers to the monitoring and evaluation processes which underlie thinking. From the perspective of creative cognition, metacognitive processes mainly involve the selection and evaluation of ideas and the selection of strategies to better generate ideas (Lebuda & Benedek, 2023; Puryear, 2016). Crucially, these models, and others of creative metacognition, show idea generation and evaluation as an iterative process in which ideas are generated, trialled and then retained or discarded (Campbell, 1960; Simonton, 2010, 2023). In common with all other phases of the SCM, this stage is considered as distributed across people and things. Ideas are trialled and refined through dialogue, sketching or other forms of making (here making extends to the crafting of scientific experiments).

Discussion

This paper introduces a framework for collating the cognitive processes that underlie serendipity. It suggests that we need to consider three main aspects of the serendipitous process: First, a prepared mind which is hypothesised to consist of both an informational and an attentional state; Second, an accident which is noticed and selected; Third, a cycle of amplification and verification. All three stages are distributed across people and things, drawing from theories of the cognitive extension to understand the contingency of involvement with an environment in flux. A key contribution of the SCM is to move away from a linear model of serendipity to examine how, over time, sub-personal acts of noticing can reach a threshold explaining findings such as the phenomenon of missed serendipity. Crucially, by moving away from self-reports, the SCM offers is a way of identifying moments when serendipity does *not* occur in a facilitative environment.

The Relationship Between SCM and Other Models of Serendipity

SCM is not the first model of serendipity. Many researchers have aimed to develop a model to explain the complexities of this process. In their systematic review of serendipity in human information behaviour, Liu et al., (2021), separate the different models into three types. The largest type of model is process-oriented which look at the modular components that contribute to serendipity, alongside these are context-based models which examine the importance of the environment followed by ontology-oriented, that is models which examine the nature of serendipity. Others are integrated and aim to combine all of these. The SCM aims to be an integrated model which takes into account the process of preparing for and noticing an accident, makes the observation that the ontology of serendipity needs to encompass action over time and importantly, does not create boundaries between those processes which occur in the environment or those which occur in the head, leading to a model which sees context as an essential component throughout.

There are several important overlaps between this model and other existing models which it is worth highlighting. First, many models lay an emphasis on a conscious recognition that there is an event of interest that accompanies a serendipitous event. For example, Erdelez and Makri's (2020) updated model of serendipity in information encountering (IE) and SCM emphasise the importance of the information encounter leading to a noticeable disruption or suspension (either permanent or temporary) of the initial task. Like SCM, the IE model places an emphasis on conscious noticing of the unexpected piece of information. This same "act of noticing" is central to Rubin et al.'s (2011) model of serendipity. McCay Peet and Toms' (2015) model focuses on the nature of the 'trigger' event in which something external to the individual serves as catalyst for the change underlying serendipity. Thus, the exclusion of the subliminal priming or unnoticed environment fluctuations from the SCM is in line with the majority of existing models.

Second, the importance of the amplification of the serendipitous event reflects other models of serendipity. Lawley and Tompkins (2008) have a similarly iterative phase to their model of serendipity discovery in which the potential is recognised evaluated and amplified. The recognition of the potential of an event and the effort expended to realise that potential is also central to Makri and Blandford's (2012) model of serendipity in which the trigger moment is only the start of the process of a serendipity. Crucially for both these models and indeed, for other such as IE this process of assessment of potential value is an ongoing one which can lead to the accident information being discarded after further exploration. What the SCM adds to the existing models is an understanding of how the discarding of this information can still lead to an updated epistemic state. By drawing on the Seifert et al's concept of markers or indices, the SCM places the serendipitous moment in a longer chain of ongoing sense making and offers an explanation for the particular resonance of certain pieces of information beyond the characteristics of that information.

Limitations

It is a truism that models of processes are necessarily reductionist (Box, 1976; Smaldino, 2017). In the case of serendipity, this focus is both necessary and perhaps unsatisfactory. It is not suggested that the reductionist model presented here can fully explain serendipitous moments. Whether weakly or strongly emergent, it is unlikely that the simplified model here can explain its prevalence or its importance. However, the overarching aim of the SCM is to provide a way to disentangle generating value from unplanned events from the sense of having experience a moment of serendipity. For this reason, it is not based on empirical data as other models are but instead draws on related concepts from various domains.

There are three key aspects to serendipity that do not feature in the model and yet are likely to be important. The first is the notion of internal or endogenous serendipity as outlined by Simonton (2022) and Gilhooly (2022) in which the event which triggers a new thought is not one which comes from the environment but one which arise from the stochastically informed unusual associations of ideas. Both Simonton and Gilhooly give the example of the famous mathematician Poincaré having a sudden realisation about the nature of a type of Fuschian function with no obvious external prompt and point out that creative thoughts often come about at a moment of mindwandering. Gilhooly draws on the highly interconnected nature of semantic networks to show how chance events might arise on the neural level. What marks the internal nature of this internal serendipitous event is the moment of surprise. The thinker is surprised by the unusual combination of thoughts. Therefore, while the SCM is designed to address external serendipity, that is serendipity sparked by an external event, there is no reason why it could not similarly be applied to internal serendipity. Indeed, the attention to the underlying cognitive state of the agent may make it more promising that other models in this respect.

The second, although it has a focus on surprise, the SCM does not take into account the other emotions that are likely to act as motivational factors when it comes to all the cognitive processes that are outlined as part of the process. For example, the valence of information encountering may predict the extent to which it is stored or is discarded. This emotional state was evidenced in Heinström's work on personality dispositions toward encountering serendipity and features in the process of evaluation posited by Jiang et al. (2019). Thus, while surprise is an emotion consistently associated with serendipity, others may well have equal importance to the process. Similarly, the indices which here are theorised as emotionally neutral may also play a role in triggering emotional states.

The third is the notion of value or meaningfulness when it relates to the serendipitous moment. SCM posits that a noticed accident is meaningful (and therefore inherently valuable) for subsequent amplification, but the nature of that value is still to be determined. On a personal level, the value could lie in completing the unfinished task but this does not explain larger scale serendipitous moments where the value and the discovery are co-created. Thus, moving beyond the process outlined above, it is plausible that serendipity could operate on multiple timescales requiring not just the trigger accident but also a surrounding system that accords value to the discovery (Ross, 2022b). Work in organisational psychology which examines the social structures necessary to support serendipity may point to an additional layer to SCM (Busch, 2022; Cunha et al., 2010).

Conclusion

The proposed model for examining serendipity from a cognitive perspective outlined in this paper is designed for prospective experimental research into serendipity in the process of its unfolding rather than in the retrospective understanding of the person experiencing it. It draws on theories of cognition to suggest a detailed model of the process of recognising and exploiting an accident. The moment of noticing the accident is predicted to arise from the informational and attention states of the individual agent and the characteristics of the accident. The process of serendipity extends beyond this point and SCM propose a cyclical model in which even information which is unused is theorised to lead to an updated state and will perhaps be recycled in later serendipitous moments. The final aspects of serendipity, its verification and amplification is consciously dependent on the characteristics of the person and of the surrounding socio-cultural environment.

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