Serendipity and inherent non-linear thinking can help address the climate and environmental conundrums

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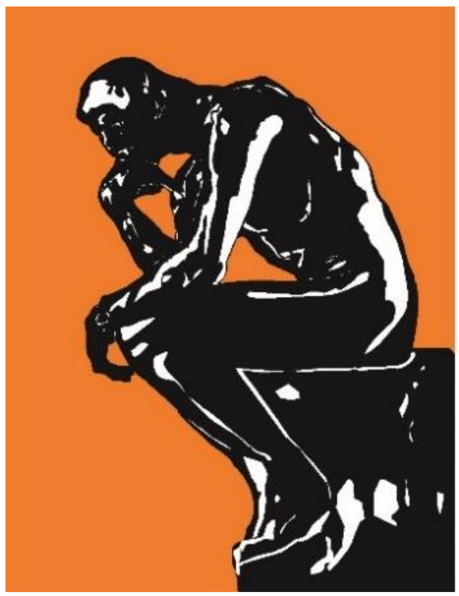

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"– Great Master, what is its use if the hook cannot catch fish?

Kingfisher the Wise replies solemnly: – Straight hook was once used to catch... an emperor."

In "The Weirdest Fishhook"; *The Kingfisher Story Collection* (2022a)

Abstract

Humankind is currently confronted with a critical challenge that determines its very existence, not only on an individual, racial, or national level but as a whole species: the fight against climate change and environmental degradation. To win this battle, humanity needs innovations and non-linear thinking. Nature has long been a substantial information source for unthinkable discoveries that save human lives. The paper suggests that by understanding the nature, emergence, and mechanism of serendipity, the survival skill of humans, humanity can capitalize on it to learn from nature and generate nature-based innovations that can address the climate and environmental degradation crises. In the era of Artificial Intelligence (AI) proliferation, AI will be a vital tool providing navigational and useful information to leverage the power of serendipity in climate and sustainability science. However, an eco-surplus culture that incorporates core values pertaining to nature and sees environmental sustainability as the conscience of the times needs to be built to direct and control the immense power of AI-leveraged serendipity. Insights applied in this paper are drawn from the book titled "*A New Theory of Serendipity: Nature, Emergence and Mechanism*".

Keywords: unthinkable discoveries; humanities; artificial intelligence; A.I.; information processing creativity; non-linear thinking; war; survivability; philosophy of science; philosophy of AI; community science; citizen science

Values of serendipity: Revisiting the old, contemplating the new

In 1930, the Institute for Advanced Study (IAS) was founded in Princeton, New Jersey, by American educator Abraham Flexner, together with philanthropists Louis Bamberger and Caroline Bamberger Fuld. The goal and guiding principle in founding the Institute are peculiar, as Flexner (1939) implied: "unobstructed pursuit of useless knowledge". To accomplish this goal, IAS has diligently invited and gathered the most brilliant minds, like Albert Einstein, J. Robert Oppenheimer, Hermann Weyl, John von Neumann, Kurt Gödel, etc. The so-called "useless knowledge" is, in fact, the power of science and the sublime beauty of intellect. The process of seeking knowledge is always filled with seemingly useless information at first glance. However, under some specific conditions, scientists will later realize its immense hidden value. And that is the beginning of a creative mechanism that makes up the majority of scientific discoveries: serendipity.

Serendipity has generated significant curiosity and excitement, particularly within the scientific, creative, and business realms, since the 1950s when Merton and Barber (2004) wrote the book "*The Travels and Adventures of Serendipity*". The phenomena that the term "serendipity" demonstrates have been under many major breakthroughs in human progress. The unexpected advantages and merits generated by/from serendipity are so stark that scientists usually refer to it as chance, fate, luck, destiny, karma, coincidence, providence, etc.

(Napier & Vuong, 2013; Sethna, 2017). Some researchers suggest that both luck and skills are required for serendipitous discoveries (André et al., 2009; Copeland, 2019). However, they mostly focus on cultivating serendipity for applications and lack examination of the underlying mechanism leading to serendipity. To effectively capitalize on the vast power of serendipity, a novel understanding of its nature, emergence, and mechanism is needed. In this essay, we aim to employ the new theory of serendipity to demonstrate how the underlying mechanism of serendipity will be a special weapon of humankind in taking advantage of biological systems, from our daily beverages and annoying pests like insects to precious species such as algae and seaweed (which are also delicious to eat), to address the existential threats of climate change and environmental degradation.

The new theory of serendipity posits that serendipitous discoveries are not as unpredictable and uncontrollable as previously thought (Vuong, 2022b). It proposes that the process leading to serendipitous discovery is conditional rather than unexpected or accidental. Specifically, serendipity is defined by the theory as "an ability to notice, evaluate, and take advantage of unexpected information for survival purposes (both natural and social), of which the outcome and success rate are conditional on the individual (or organizational) mindset and environment" (Vuong, 2022b). Following this definition, in addition to being a conditional process, serendipity is also fueled by humans' survival needs in both the natural and social environments. This notion can be typically reflected through the discovery processes of fire and pharmaceuticals, typically penicillin. The former discovery was derived from the long-term encounter with fire in the natural environment (e.g., bush fire, forest fire, volcano, etc.) and used to protect humans from the dark, cold, and dangerous predators, as well as advance technological progress (Gowlett, 2016). The latter discovery, resulting from the accidental observation of *Penicillium* mold by Alexander Fleming, has changed medicine's course and saved uncountable lives from infection-induced mortality (Gaynes, 2017).

Wars, which are undoubtedly factors affecting human survivability, have long been sources of innovations; for instance, breakthroughs in manufacturing processes and systems in Great Britain during the glorified Industrial Revolution in the 18th and 19th centuries are suggested to be encouraged by wars (Satia, 2019). Currently, humanity has to deal with a crucial struggle that defines its very survival, not just as individuals, races, or nations, but as a whole species: the battle against climate change and the deterioration of the environment. To win this battle, humanity needs innovations.

Nevertheless, artificial technological pathways at the current pace face the risks of not being successfully developed and sufficiently scaled up (e.g., electrifying end-use sectors, carbon capture, utilization, and storage to remove CO2 from the atmosphere, low-carbon hydrogen and hydrocarbon fuels, and bioenergy utilization, etc.). According to the International Energy Agency (2020), in order to attain net-zero emissions by 2070, almost 40% of the total reduction in emissions will depend on technologies that have not yet been widely embraced by the market and are still in the early stages of development. Meanwhile, the other 35% of the total reduction in emissions needs to be achieved by technologies still in the prototype or demonstration phase.

Fortunately, there is glimmering hope in the climate change and environmental degradation battles as humankind can learn from nature, of which we (humankind) have been a student since the dawn of civilizations. This bad student has disturbed the ecological balance and must learn how nature heals itself to correct the mistakes. The student needs the humanities to do that.

So, what weapon does the student have to learn from nature?

It is serendipity, a vital weapon in scientific discoveries! Serendipitous discoveries, especially those from observation of nature, can be key solutions for humankind in the current existential crisis.

Light of hope: Examining valuable innovations and their promises

In essence, serendipity is a type of information processing capacity promoting changes in perception and action, stemming from (and having the nature of) the need to develop survival skills. Survival skills are commonly observed in the wild and can still be observed in human society through social forms (e.g., competencies for jobs and career progress, etc.). The serendipity mechanism works to detect values through the mind's processing of information stored in the memory and absorbed from the external environment, making it difficult to determine the time and space of its occurrence (Vuong, 2022b, 2023). Because of its elusiveness, difficulty in training, and the randomness of when information value is identified, serendipity is often confused with "luck" (Busch & Barkema, 2022; Makri et al., 2014).

However, when viewing serendipity as a conditional process, the likelihood of serendipitous occurrences can be improved by meeting the following conditions (Napier & Vuong, 2013; Vuong, 2022b): 1) the availability of information, 2) appropriate directions, 3) disciplined process, 4) sufficient openness and observing abilities, and 5) sufficient experience, knowledge, wisdom, and abilities. Although all these conditions are required for the serendipity to be encountered and attained, each condition's degree will vary per scenario, and the sequel for meeting these conditions will also be different. Moreover, the outcome generated by a prior serendipitous process can be used as input in processes leading to other serendipity as long as it helps achieve the necessary conditions for the serendipity to happen.

Recent innovations springing from nature observation to solve climate and environmental degradation problems have demonstrated the power of serendipity: plastic-eating larvae, coffee-constituted concrete, and carbon-sequestration algae.

Plastic-eating wax moth larvae

Plastic pollution is a major global concern that adversely affects multiple geophysical processes and properties (e.g., global carbon cycle, nutrient cycle, soil properties, etc.) and worsens biological integrity (MacLeod et al., 2021). The problem is expected to intensify as plastic production has doubled in the last two decades and has seen no peak (Ritchie et al., 2023). Federica Bertocchini's accidental discovery of wax moth larvae's plastic digestion capability has helped the world to recognize that biologically based recycling can be an answer to environmental pollution, and the Earth's ecosystem has a tremendously useful "ecosystem service" that can tackle the global plastic trash catastrophe that is harming global ecosystems.

In 2017, Bombelli et al. (2017) published a brief report showing the wax moth larvae (*Galleria mellonella*)'s ability to degrade Polyethylene, the most common packaging plastic, rapidly. This finding was derived from an accidental observation of Federica Bertocchini, a molecular biologist, when caring for beehives near her home. A swarm of parasitic caterpillars was causing disturbance to one of the beehives. Within this group of troublesome organisms were the larvae of wax moths, recognized for their insatiable and ruinous hunger. Bertocchini gathered the caterpillars, placed them inside a small plastic bag, and proceeded with her beekeeping responsibilities. Upon retrieving the bag some hours later, she observed an anomaly: small holes had appeared (Ong, 2023). The scientist's curiosity was aroused, and she promptly made significant inquiries:

- Did these caterpillars only puncture the plastic bag, or did they modify its chemical composition?

Expedient experiments in her laboratory substantiated that a constituent in the caterpillars' saliva had deteriorated the plastic bag. This information led to the 2017 scientific finding that the larvae of the wax moth can biodegrade Polyethylene remarkedly faster than the rate of PET biodegradation by a bacterium (*Ideonella sakaiensis*) formerly reported (Yoshida et al., 2016). In 2022, Bertocchini and other colleagues continued to publish a more detailed study of the wax moth's polyethylene degradation capability. Specifically, the saliva of wax worms has the ability to overcome the bottleneck stage of polyethylene biodegradation, known as the initial oxidation step. The effect is generated by two enzymes from the phenol oxidase family found in the saliva of the wax moth (Sanluis-Verdes et al., 2022). The finding was expected to pave the way for developing water-based enzyme solutions that could be implemented by waste processing plants or at-home plastic waste kits, facilitating the distribution of the technology. The outcomes from the biodegradation process are natural components, such as ketones or alcohol, which can be safe for release or reuse in other processes (The Learning Network, 2023). Federica Bertocchini also established Plasticentropy (https://www.plasticentropy.net/manifesto/), a company that uses "insects to identify, characterize and eventually deploy insect enzymes to degrade plastic residues into recyclable small molecules".

From the case of Bertocchini, it can be seen that essential conditions must be achieved to transform accidental observation into remarkable scientific discovery and, subsequently, the establishment of a startup. In the discovery of Bertocchini, observing abilities, openness, and disciplined process seemed to be key conditions that made serendipity happen and be attained. Apparently, if Bertocchini could not observe the small holes in the plastic bags and were not curious enough, she would not have conducted the subsequent experiments and studies. What was noteworthy was that Bertocchini's research direction at the time was about the early embryonic development of vertebrates but not insects and their capacity to degrade sturdy polymers. Her openness to new knowledge and willingness to explore out-of-discipline topics and collaborate with other colleagues was, therefore, a prerequisite for later scientific discoveries and the startup establishment.

In addition, her disciplined process of working, exploring, learning, collaborating, and experimenting is another key condition that allows her and her colleagues to capitalize on the initial accidental observation and turn it into bio-based solutions for plastic recycling. The desire to pursue sustainable development and formerly accumulated knowledge in molecular biology, organic synthesis, and polymer science were also required during the process of actualizing the serendipity. Without them, Bertocchini would not have sought sustainable ways to reduce waste and be capable of making hypotheses about the reason behind the plastic bag's chemical structure degradation or conducting experiments.

Coffee-constituted concrete

Disposal of organic waste can generate significant greenhouse gas emissions, including methane emissions from anaerobic fermentation that produces landfill gas. In 2023, a team of researchers and engineers at RMIT University discovered how to recycle coffee grounds to produce construction materials instead of letting them decompose and emit greenhouse gases. This method not only helps to create values for an estimated 508 million kilograms of used coffee grounds a day globally but also offers hope for recycling other types of organic materials generated as byproducts from agricultural activities and food production processes. The discovery also helps reduce the pressure on sand and gravel exploitation and strengthen the concrete by roughly 30% (Roychand et al., 2023).

Specifically, in order to incorporate coffee grounds into concrete, the authors employed a roasting method that is not dissimilar to roasting coffee beans for extracting flavor, which is called pyrolysis. Pyrolysis is a process of heating the coffee ground to around 350°C in the absence of oxygen to turn it into biochar. If raw coffee grounds are added to concrete, the concrete made with raw grounds has a significant decrease in its strength compared to the control concrete after 28 days. The higher the amount of coffee grounds added, the worsened the concrete's strength. However, if 10 or 15% of sand is replaced by biochar generated from pyrolysis at 350°C, the concrete is 30% stronger than the control concrete. The strength of the concrete with greater percentages (20%) of biochar is similar to that of the control.

The serendipitous process leading to the actualization of the idea is no less conditional than that of the discovery of plastic-eating wax moth larvae. The idea accidentally arose in the author's mind when they noticed the quantity of coffee cups they were personally consuming and wanted to find a solution for organic waste recycling. Without this vital observation and the openness to test new ideas, the experiment would not have occurred. It should be noted that all the authors were residing in Melbourne, the city that considers itself the mecca of cafe culture in Australia, when they conducted the research (Vinall, 2023). Thus, it is plausible that their coffee consumption habits were more or less affected by the surrounding socio-cultural environment, contributing to the inspiration sparking the scientists' idea to experiment.

Many other people were also living in similar city and might have similar observations and ideas to the study's authors, but why have they not made a similar discovery? Although the environment and the scientists' adequate observation and openness were crucial conditions for serendipity, their knowledge, abilities, and experiences in the fields of material science and engineering were also prerequisites for taking advantage of the serendipitous idea. These factors allowed them to design the experiment, curate and analyze the materials, conduct pyrolysis, and test the results. If the experiment were poorly designed by plainly adding the coffee grounds, the scientists would not have found the remarkable potential of coffee grounds, as adding raw coffee grounds will release the organic compound and weaken the concrete's compressive strength.

Carbon-sequestration algae

Numerous solutions have been proposed to capture and sequester carbon to confront the climate and environmental degradation crises. One of the most crucial and effective methods today is the biosequestration of carbon through algae. Both macroalgae and microalgae show significant potential in reducing greenhouse gas emissions, mitigating ocean acidification, and contributing to national energy security (Moreira & Pires, 2016). Additionally, carbon capture and sequestration through algae are viewed as environmentally friendly and economically feasible and contribute to sustainability in the long term (Basu et al., 2014; Editorial, 2023).

Although the carbon capture and sequestration capabilities of algae are not recent developments, understanding and harnessing the power of these seemingly trivial organisms to address our existential crisis requires a continuous discovery process. During the process, unexpected events and observations are frequent and play a crucial role.

Discovery requires a foundation of scientific knowledge, and this necessitates financial investment. Interestingly, the initial significant investments in research on biofuels from algae occurred in the 1970s when oil supply was constrained due to the Organization of the Petroleum Exporting Countries (OPEC) embargo against the United States during the Arab-Israeli War. Fearing instability in oil supply affecting energy demand, major oil companies began investing in multiple types of energy, from solar and nuclear energy to lithium batteries and bio-diesel made from algae (Westervelt, 2023). On the government side, the U.S. Department of Energy initiated the Aquatic Species Program in 1978 to explore the potential of energy production from algae. This program provided $25 million over 18 years to develop algae-based liquid fuel that is competitive in price with petroleum-derived fuels (Sheehan et al., 1998). While most of these investments ended when the oil market hit bottom in the 1980s and 1990s, the research findings on algae during that period laid the groundwork for discoveries regarding algae's climate change mitigation potential in the last two decades.

Among multiple pathways of carbon sequestration using algae, releasing iron into the ocean to stimulate algae growth is a promising approach. The iron release can cause a massive algal bloom that rises to the water's surface, absorbs CO2 from the air through photosynthesis, and eventually sinks into the ocean, forming carbon reservoirs. Before 2009, the United Nations (UN) banned this artificial approach due to concerns about negative impacts on the ecosystem. However, accidental observations in Antarctica revealed that this mechanism had been naturally functioning for millions of years in isolated southern sea areas, which convinced the UN to lift the ban on this direction of carbon sequestration. Subsequently, it provided the opportunity for Smetacek et al. (2012) to complete their study, which helps understand how algae and iron interact to sequester atmospheric carbon in the marine ecosystem and provides the method to employ iron-fertilized diatom to sequester carbon for centuries in the ocean bottom or for longer in the sediments.

Besides serendipitous observations and events, a disciplined process of observation, exploration, accumulation, and sharing of knowledge related to the characteristics and effects of algae is crucial for humankind to capitalize on the organism’s potential. This disciplined approach brings us closer to nature-based solutions previously unimaginable to fight climate change, such as reducing methane emissions in livestock farming (CBS News, 2021) or sequestering carbon in deserts (Buckley, 2023).

Hope for humanity, from the humanities

While there are just three instances, they reflect humankind's hope, not only in terms of knowledge and technology but also, more crucially, in terms of humanities. This hope is expressed in a basic common shared by all three examples: the bond between scientists and nature. The link promotes the fulfillment of two essential conditions for encountering and utilizing serendipity. The natural connection helps scientists to sense the possible significance of seemingly 'trivial' information from nature, such as contact with insects, detecting the pores on a plastic bag, or the value of coffee grounds. From there, they applied the accumulated scientific and technical knowledge to capitalize on the opportunities. Without a prepared mind to accept these 'miraculous' pieces of information from nature, can we recognize and harness the value of such information? The quotation from Louis Pasteur may answer this question:

“In the fields of observation, chance favors only the prepared mind.”

Aside from the capacity to perceive and exploit the value of information, their connection with nature makes them aware of the threat to humanity's existence and continued development if the environment around them, in particular, and the Earth's ecosystem in general, deteriorates. This sense of danger, coupled with their survival needs in society (e.g., career), are the primary forces driving their perceptions, thoughts, and behaviors. The sense is also the factor enabling the humanities to recognize mistakes, correct them, and apply the 3D process (use the best knowledge within the discipline and connect to the best knowledge out of discipline following a disciplined process) to make them right, thereby creating unthinkable discoveries through serendipity (Nguyen et al., 2022; Vuong, 2022b; Vuong et al., 2022).

How to leverage the power of serendipity in climate and sustainability science

Since the early days of humanity, serendipity has been a special weapon that has supported humans in prolonging their existence and development. Now, facing the existential threats from climate change and environmental degradation, humans must capitalize on this survival skill. Nature has always provided us with unexpected and valuable things. It has the capacity to maintain a relative equilibrium and create biological systems that are highly appropriate for survival. Since serendipity relies heavily on various sources of information, observing nature to find innovative nature-based solutions to solve environmental challenges is feasible and promising (Maes & Jacobs, 2017; Nguyen, Le, et al., 2023; Seddon, 2022).

As artificial intelligence (AI) grows more significant as a source of information, humans will undoubtedly spend more time interacting with it, even more than with other people around them (Vuong et al., 2023). Due to its capacity to seek, collect information, and synthesize data from existing sources, AI will be an immensely significant tool, providing navigational and useful information to meet conditions leading to the emergence of and actualizing natural-based serendipity (Vuong & Ho, 2024). AI is currently being used to synthesize chemical compounds for drug synthesis, solve complex problems, and reduce the language barrier (Coley et al., 2019; Joksimovic et al., 2023; Lee, 2023; Liu et al., 2021). If applied appropriately, this will result in leveraging the power of serendipity. Due to the power of AI, it must be undertaken with the utmost prudence. If climate change deniers gain control of the power, attempts to address climate change and global environmental deterioration will be jeopardized.

Furthermore, investing in environmental research, in particular, and other scientific fields, in general, is critical since it contributes to expanding humanity's knowledge base, an essential resource for the serendipity process. With insufficient funding for science and environmental-related technological spinoffs or startups, serendipitous observations and ideas will remain mere thoughts without tangible manifestation. How many scientists will be motivated to create and innovate natural solutions if their own existence is not guaranteed? Investing in research is expensive, but if it can assist in tackling dangers to people's lives, it is always an economical decision (Vuong, 2018). Suppose environmental-related technological spinoffs or startups are properly and timely invested in. In that case, it may help create a sustainable financial source and effectively scale up the effects of the scientific findings.

Furthermore, eco-surplus culture is critical for humans to harness the power of serendipity combined with AI to address climate and environmental deterioration problems (Nguyen & Jones, 2022; Vuong, 2021). Human cultural value systems need to include values related to nature and see environmental sustainability as the conscience of the times. To achieve this, we must build a bond between humans and nature through empirical science, community science, arts, literature, lived experiences, and even ancient artifacts (Vuong, 2020; Vuong & Nguyen, 2023). At a time when direct contact with the environment is diminishing due to urbanization, and humans spend most of their time communicating with machines, synthesized environmental information provided through AI will lead to 'serendipity moments' that help shape people’s humanistic values containing love for nature. If this process persists and lasts long enough, it will help form an eco-surplus culture (Nguyen, Nguyen, et al., 2023).

Establishing an eco-surplus culture will be foundational to utilizing the strength of community and citizen science to cultivate serendipity. Scientists are not the only people who can observe nature; other people in society can also do so. Relying solely on empirical science will disregard the opportunities to utilize the knowledge systems accumulated by communities and the wisdom distilled through lived experiences (Binley et al., 2021; Dickinson & Bonney, 2017; Vuong & Nguyen, 2023). With vast knowledge systems and relative differences between empirical science, community science, citizen science, and wisdom, AI will be a useful tool to help synthesize, compare, connect, and generate unexpected and valuable combinations for the serendipity encounter and attainment.

While Louis Pasteur developed the rabies vaccine and Alexander Fleming discovered penicillin for saving uncountable lives, what about curing the ailment of the Earth's declining health?

A thorough understanding of serendipity will help humans reach untapped knowledge and lived experiences in nature for one goal: saving the life of the Earth and securing a habitable habitat for all.

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