Prigogine's Perspective on Nature

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Abstract

Along the history of mankind, we have been attempting to understand nature in various ways. The way we understand nature in each period seems to have very much influence upon the way of thinking and living of the people. Through this work, I want to study Ilya Prigogine, the Nobel Prize winner on the second law of thermodynamics at nonequilibrium system. With Prigogine's perspective on nature, we could learn the limits of the Newtonian mechanical worldview. With Prigogine's the evolutionary process, a new perspective should be attained instead of the Newtonian worldview. And this perspective should be one of the possible answers to reestablish a new relation between man and nature.

Introduction

Our perspective on nature has changed throughout history and at the same time has affected directly or indirectly our relation to nature. The mechanical worldview of Newtonian physics is confronted with limitations and perceived as too narrow because of new discoveries from Einstein and quantum physics. The old scientific paradigm was released if new discoveries were strong enough to replace the old one. Tito Arecchi, in the article *Chaos and Complexity*, says about the latest scientific revolution, "People now speak of a third revolution in physics, to follow the first one sparked off by Galileo and Newton, and the second, which took place during the first decades of this century and laid the foundations of relativity and quantum mechanics. This third wave may be called the physics of complexity" (Arecchi, 1992, p.350). Arecchi spoke about the new scientific revolution on chaos theory and the science of complexity in which Prigogine did agree that we came to the period of transition and pointed out some characteristics of the new science by mentioning to Yvor Leclerec and Jacob Bronowski.

> Mankind is at a turning point, the beginning of a new rationality in which science is no longer identified with certitude and probability with ignorance. We agree completely with Yvor Leclerc when he writes, 'in the present century we are suffering from the separation of science and philosophy which followed upon the triumph of Newtonian physics in the eighteenth century.' Jacob Bronowski beautifully expressed the same thought in this way: The understanding of human nature and of the human condition within nature is one of the central themes of science. (Prigogine, 1997, p.7)

The need for the new worldview, therefore, is to open the channel to communicate between philosophy and science, which can help us reflect our own selves and also reestablish our relations with nature. Knowledge should not just be the way for obtaining power to conquer, or worse than that to exploit greedily without any limitation. Nature does not stand as dead matter waiting for human exploitation. We once alienated from the world we lived under the influence of the mechanical worldview. Prigogine realized that modern scientific worldview did not bring only the rapid progress in advance technology but also the tragic isolation of man from nature.

> The success of Western science is a historical fact, unpredictable a priori, but which cannot be ignored. The surprising success of modern science had led to an irreversible transformation of our relations with nature… Science initiated a successful dialogue with nature. On the other hand, the first outcome of this dialogue was the

> discovery of a silent world. This is the paradox of classical science. It revealed to men a dead. Passive nature, a nature that behaves as an automaton which, once programmed, continues to follow the rules inscribed in the program. In this sense the dialogue with nature isolated man from nature instead of bringing him closer to it. A triumph of human turned into a sad truth. It seemed that science debased everything it touched. (Prigogine & Stengers, 1984, p.5-6)

Nature and the Science of Complexity

One of Prigogine's main tasks is to reestablish our relations with nature on the basis of a new understanding in which nature and we are not isolated from each other. If the old mechanical worldview leads to alienation and we now know precisely of its own limitations, we will have to search for a new more proper relationship with nature. Einstein's theory of relativity and quantum mechanics have played central roles in understanding the universe. However, Newtonian physics still works well in a more limited way. The three main theories play in different parts of the universe unveiling the complex characters of the universe. The richness of nature, then, cannot be reduced into one single formulation as Prigogine put it, "Our universe has a pluralistic, complex character. Structures may disappear, but also they may appear. Some processes are, as far as we know, well described by deterministic equations, but other involve probabilistic processes" (Prigogine & Stengers, 1984, p.9). By this view, it seems to be that Prigogine accepts both Newtonian accuracy and quantum probability. It might be an impossible task for traditional scientific reductionism to combine these two different theories. But for the new science of complexity, Prigogine came to reconcile the two different views in the same process. This new synthesis will probably encourage us to consider the creativity of nature, which is 'active', than 'passive' like the dead matter in the mechanical worldview. The richness of nature is always full of surprises, novelties and the unexpected. According to Bohr's principle of complimentarity, we are not separated from the processes of nature; we are both 'actor' and 'spectator.' We are not cogs in the cosmic machine, and nature is not 'out there' to be explored. Nature and ourselves are entwined within the same processes. To understand nature is probably the way to understand our own selves.

Prigogine considered quantum discovery as a new road to help us come closer to nature. Newtonian physics explains nature in the deterministic way through which we can predict the future and retrodict the past if we have enough information about the present whereas in quantum mechanics, on the contrary, everything ends with probability as we know by Heisenberg's uncertainty principle. Prigogine reminded us of Whitehead who said, "A clash of doctrines is not a disaster – it is an opportunity" (Whitehead, 1953, p.186). Prigogine undoubtedly took this opportunity to overcome the dichotomy of deterministic view and pure chance, being and becoming, order and chaos through the way which gets along well with 'process philosophy' of Whitehead whom he mentioned more than any others in his explanation.

> Whitehead understood perhaps more sharply than anyone else that the creative evolution of nature could never be conceived if the elements composing it were defined as permanent, individual entities that maintained their identity throughout all changes and interactions. But he also understood that to make all permanence illusory, to deny being in the name of becoming, to reject entities in favor of a continuous and ever-changing flux meant falling once again into the trap always lying in wait for philosophy – to 'indulge in brilliant feats of explaining away. Thus for Whitehead the task of philosophy was to reconcile permanence and change, to conceive of things as process, to demonstrate that becoming forms entities, individual identities that are born and die. (Prigogine & Stengers, 1984, p.95)

In order to understand the complexity of nature, he followed Whitehead in the sense that we need not choose between Newtonian deterministic physics or quantum physics of pure chance. We need a new synthesis of the two, and this new synthesis has to be explained in terms of process rather than things. By this way, nature could not be understood in form of separated entities, but, on the contrary, it should be viewed relevant to what Whitehead said, “The physical world is bound together by a general type of relatedness which constitutes it into an extensive continuum” (Whitehead, 1978, p.96). Prigogine, in the *Preface of his book Order out of Chaos*, introduced the changing perspective on nature, “In the classical view, the basic processes of nature were considered to be deterministic and reversible. Process involving randomness or irreversibility was considered only exceptions. Today we see everywhere the role of irreversible processes of fluctuations” (Prigogine & Stengers, 1984, p.xxvii).

The turning point from reversible to irreversible process was regarded as the central role in his perspective on nature. A reversible process is in agreement with the teaching of Newtonian physics which explains all the systems in terms of determinism. The system begins and returns to the point where it begins exactly like the gradual stretching and returning of a spring. The stability of reversible process can help man determine accurately the whole system corresponding to our old belief that work and heat are interchangeable by the laws of dynamics. And this kind of system leads man to view time as reversible-time, i.e., we can predict the future and retrodict the past by our present time. For reversible process, there will have no fluctuation, no interrelation among systems. Prigogine commented that reversible process was not relevant to our actual world, “If the world were formed by stable dynamical systems, it would be radically different from the one we observe around us. It would be a static, predictable world, but we would not be here to make the predictions. In our world, we discover fluctuations, bifurcations, and instabilities at all levels. Stable systems leading to certitude correspond only to idealizations, or approximations" (Prigogine, 1997, p.55). The complexity of nature could not be known on the basis of the reversible process because nature is not dead matter like machine. The stability of reversible process that leaves no room for fluctuating is considered as a 'closed system' concerning which John Briggs and F. David Peat explained some characteristics of this system.

> Nothing new enters or leaves a closed system. The system has clearly defined parts. For maximum efficiency these parts must keep to a fixed regime. They can only operate within very narrow ranges. A part can be replaced, of course, but the system itself doesn't make such repairs. That help has to come from the outside - usually in the form of a machine… Thus closed systems always involve equilibrium or near-equilibrium situations. (Briggs & Peat, 1984, p.162-163)

The stability of a closed system in reversible process could be pictured like a steam engine that works in a mechanical repetitive way. In the gigantic clockwork of the Newtonian worldview, we have been taught that nature is programmed to repeat regularly the same order. Randomness and disorder were exceptional cases that had to be subsumed into the regular order in a mechanical system. A smooth continuity without randomness and disorder became the ideal of all systems and also the perfect form of our knowledge about nature. Now, we learn that our ideal has to be changed dramatically by the new physics. Paul Davies, in his book *God and the New Physics*, states, "But the new physics soon revealed more than simply a better model of the physical world. Physicists began to realize that their discoveries demanded a radical formulation of the most fundamental aspects of reality. They learned to approach their subject in totally unexpected and novel ways that seemed to turn commonsense on its head and find closer accord with mysticism than materialism" (Davies, 1983, p. vii).

Nature and Irreversible Process

The radical reformulation from the Newtonian perspective to the new perspective, for Prigogine, comes from his study in physics especially from the second law of thermodynamics of nonequilibrium system which emphasizes irreversibility and randomness instead of the reversibility of the closed system. He said about this reformulation, "We have discovered that far from being an illusion, irreversibility plays an essential role in nature and lies at the origin of most processes of self-organization. We find ourselves in a world in which reversibility and determinism apply only the limiting, simple cases, while irreversibility and randomness are the rules" (Prigogine & Stengers, 1984, p.8). While the limits of Newtonian physics became the fortunate error for the new discoveries of Einstein and quantum theory, a closed system of reversible process prepared the way for the new vision of irreversible process, irreversible process has its origins in the second law of thermodynamics. The second law of thermodynamics proposes the notion concerning the running down of the universe and the increasing of the entropy. In general, the total entropy always increases in irreversible processes. The entropy of the universe increases in all natural processes. In order to catch the main difference between reversible and irreversible processes, we may consider from this comparison by Briggs and Peat.

> The ideal reversible processes are totally gentle, free from shocks, sudden movement, friction, and violent flows of energy. Irreversible processes are just the opposite. Their sudden changes, shocks, turbulence, and explosiveness act to disturb the correlations between each elementary part of the system. Irreversible processes are therefore always accompanied by an increasing disorder and this is exactly what scientists mean by entropy. As the correlations and order of a system are broken down the system's entropy or disorder increases and energy that is available for useful

> work diminishes. So irreversible systems are humpty-dumpty creatures. They move in a particular direction and thermodynamically can't be put back together again. They can't be put back because of the law of increasing entropy. Reversible systems are idealized, but in reality irreversible ones are the rule and increasing entropy is everywhere. (Briggs & Peat, 1984, p.156)

The second law of thermodynamics suggests the increasing of entropy and the running down of the universe, which contradicts Newtonian mechanics. For Newtonian mechanics, time is reversible in a deterministic way that there is no "arrow of time." The increasing of entropy gives a direction to time that is irreversible the so called the 'arrow of time.' We are getting older and older, and there is no ticket to be back to be younger. The universe is running down, and the increasing of entropy pictures the nature in form of randomness and disorder. When we look around and contemplate the beauties of nature, it is easy to recognize that a disorderly arrangement is much more probable than an orderly one if the laws of nature are allowed to act without interference, e.g., the space between trees in a natural forests, the diversity of species in a tropical forest, the falling of leaves to the ground, etc. All natural phenomena reveal to us disorderly arrangement in the irreversible process of randomness. By this perspective, randomness and disorder do not happen only in exceptional cases, but in turn; they become the new rules of nature. Newtonian physics once painted nature in the frame and monochrome of an orderly system. But from now on, nature is painted with multicolor of randomness. The increasing of entropy, according to Prigogine, is the increasing of the complexity in natural evolutionary process. He attempted to explain nature with the role of irreversible process in which nature evolves in complex system. For him, irreversible processes play the central role in nature.

> Irreversibility can no longer be identified with a mere appearance that would disappear if we had perfect knowledge. Instead, it leads to coherence, to effects that encompass billions of particles. Figuratively speaking, matter at equilibrium, with no arrow of time, is 'blind,' but with the arrow of time, it begins to 'see.' Without this new coherence due to irreversible to envision. The claim that the arrow of time is 'only phenomeno-logical,' or subjective, is therefore absurd. We are actually the children of the arrow of time, of evolution, not its progenitors. (Prigogine, 1997, p.3)

Nature, understood through irreversible process, is always a "surprise." We cannot predict what will happen as the system moves from equilibrium to nonequilibrium with the arrow of time. Matter at equilibrium, according to Prigogine, is blind because it behaves in form of mechanism that repeats always the same order without any fluctuations. On the contrary, if we move from equilibrium to far-from-equilibrium conditions by the arrow of time, it will carry to the possibility of the understanding of various types of new structures. The various types of structures that occur far from equilibrium are called "dissipative structures."

> We now know that far from equilibrium, new types of structures may originate spontaneously. In far-from-equilibrium conditions we may have transformation from disorder, from thermal chaos, into order. New dynamic state of matter may originate, states that reflect the interaction of a given system with its surroundings. We have called these new structures *dissipative structures* to emphasize the constructive role of dissipative processes in their formation. (Prigogine & Stengers, 1984, p.12)

When we move from equilibrium to far-from-equilibrium conditions, it means to say that we move from a closed system to an open system. An open system always happens at far from equilibrium in which Briggs and Peat compared between a dead machine of closed system at equilibrium and a life form of open system at far from equilibrium. "In contrast to machines, life forms are 'open systems' which emerge and actually thrive in a volatile arena far from equilibrium. Open systems are able to adjust to outside changes; they takes in food, grow, replace their own parts, reproduce, and even survive the total loss of some parts – all without the aid of mechanic" (Briggs & Peat, 1984, p.163). Nature, therefore, could not be pictured in the scope of a narrow closed system. On the other hand, nature is a living system evolving in complex process leading to surprising new possibility. In our real dialogue with nature, we often are led to unexpected wonder. Briggs and Peat supported Prigogine's view at the evolutionary process by saying, "The universe can't be disassembled into simpler and simpler parts. Everything is in dynamic interaction; it is a seamless, fluid web of process structures" (Briggs & Peat, 1984, p.171). By the law of dissipative structures at far from equilibrium of evolutionary process, Prigogine insisted that the deterministic view would fail when far-from-equilibrium processes were involved. Consequently from fluctuations, systems continuously move to the dissipative structures in which he called the 'bifurcation point,' the edge of the system. He pointed out the failure of the old deterministic worldview as follows:

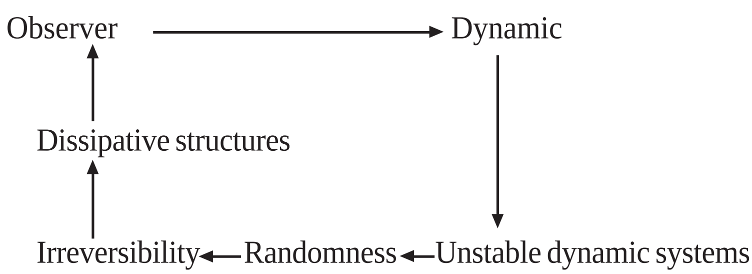
> Whenever we reach a bifurcation point, deterministic description breaks down. The type of fluctuation present in the system will lead to the choice of the branch it will follow. Crossing a bifurcation is a stochastic process, such as the tossing of a coin… We cannot predict the details of temporal evolution. Once again, only a statistical description is possible. The existence of an instability may be viewed as the result of a fluctuation that is first localized in a small part of the system and then spreads and leads to a new macroscopic state. (Prigogine & Stengers, 1984, p.177-178)

In this outlook, we probably understand what Prigogine proposed in this description by applying Heisenberg's uncertainty principle with the macroscopic of the living systems. Heisenberg's uncertainty principle limited the classical determinism at the microscopic level because we cannot measure simultaneously the position and the momentum of any subatomic particles. Prigogine's teaching of dissipative structures far from equilibrium shows that Heisenberg's uncertainty principle operates at the macroscopic level.

> For Prigogine, what happens at the bifurcation point where dissipative structures are formed is the creative moment, a macroscopic 'uncertainty principle' equivalent to Heisenberg's microscopic uncertainty principle. The observer must accept he is no longer dealing with a mechanical order that can be totally determined. He inhabits an indeterminate whole which exists beyond formulation of any particular level. In this way, the universe is as free from ultimate interpretation as a Bach cantata or a poem by Blake. (Briggs & Peat, 1984, p.200)

Nature and Prigogine's "Order out of Chaos"

Nature, from Prigogine's perspective, cannot be seen in a fixed picture like the gigantic clockwork in the Newtonian mechanical worldview. His vision on nature is beyond a formulation of any single description. Closer to his perspective, we may provisionally draw the living picture of the turbulence water in the river which sometimes flows smoothly and at other times behaves like the waterfall. The smooth flowing of water in the river can be compared with any movement of the system with a little fluctuation, which can be explained in the common situation we experience in our daily lives. The stability of the mechanical worldview may behave like water in the river without any radical turbulence. The waterfall can represent the role of dissipative structures that fluctuates the system to the various possible choices. At bifurcation point, dissipative structures play the crucial link from the old to the new and unpredictable. At the bifurcation point, new systems emerge from the old ones. It means to say that the new form of order will emerge out of disorder in the evolutionary process. "We come to one of our main conclusions: At all levels, be it the level of macroscopic physics, the level of fluctuations, or the microscopic level, nonequilibrium is the source of order. Nonequilibrium brings order out of chaos" (Prigogine & Stengers, 1984, p.286-287). Prigogine's model 'Order out of Chaos' becomes a new perspective on nature. We need to reconceptualize our idea about nature by replacing the conventional idea of 'things' with 'process.' The evolutionary process that can help us view nature in this perspective can be understood by the following diagram:



This diagram, it may help us understand more about what we have learnt from Newtonian physics and after. Nature and humankind are involved in this evolutionary process. We are both spectators and actors as mentioned by Bohr's principle of complimentarity. Prigogine reaffirms this connection.

> Demonstrations of impossibility, whether in relativity, quantum mechanics, or thermodynamics, have shown us that nature cannot be described 'from the outside,' as if by a spectator. Description is dialogue, communication, and this communication is subject to constraints that demonstrate that we are macroscopic being embedded in the physical world. (Prigogine & Stengers, 1984, p.299-300)

This form of involvement has to be grasped as the starting point of the whole process. Nature exhibits at equilibrium or near equilibrium situation without any fluctuations in the dynamic system in the form of reversible process. Newtonian explanation may be suitable for the stability of the closed system at near-equilibrium situation. If the system fluctuates from equilibrium to far-from-equilibrium situation, the system will flutter from stability into instability and randomness will play the central role under the irreversible process. With the increasing of entropy in irreversible process, the system will arrive at the bifurcation point and the role of dissipative structures will turn the whole systems into a new form of order in complex character. At the bifurcation point with much more fluctuations than an ordinary situation at near equilibrium, a small cause can change radically from the old system into a new one. For those who are trained to think in terms of linear causality will not be able to understand how a small cause can have a large effect. But for the new paradigm, we need the new tool of non-linear explanation that creates a new outlook to the radical transformation from one system to another possible one.

> It is remarkable that near-bifurcations systems present large fluctuations. Such systems seem to 'hesitate' among various possible directions of evolution, and the famous law of large numbers in its usual sense breaks down. A small fluctuation may start an entirely new evolution that will drastically change the whole behavior of the macroscopic system. The analogy with social phenomena, even with history, is inescapable. Far from opposing 'chance' and 'necessity,' we now see both aspects as essential in the description of non-linear systems far from equilibrium. (Prigogine & Stengers, 1984,p.14)

The amplification of small causes effects strongly to larger systems. This is supported by the new discovery of Edward Lorenz, a research meteorologist and mathematician working at the Massachusetts Institute of Technology, who attempts to explain metaphorically the nonlinear dynamical system with the Butterfly Effect. Lorenz's Butterfly Effect is based on the notion that a butterfly flapping its wings in Asia today can transform storm systems next month in the Atlantic. A small fluctuation at bifurcation point can cause a revolution like the stirring air of a butterfly, or a match igniting a forest. Sanders described it as follow:

> The Butterfly Effect was a major breakthrough in understanding how small systems interact with large systems. A small change in the initial conditions of one system multiply upward, expanding into larger and larger systems, changing conditions all along the way, eventually causing unexpected consequences at a broader level sometime in the future. (Sanders, 1998, p.57)

She also applied Butterfly Effect in politics, economics, business, and in society where a small cause which has tremendous impact to the larger system. The fall of communism in the former Soviet Union and throughout Eastern Europe began with the strength and the victory of the Polish worker's union – Solidarity (Sanders, 1998, p.72). She also applied this non-linear perspective to other fields. James Gleick, in his book *Chaos: Making a New Science*, considers the Butterfly Effect as the starting point of the new revolution causing the unexpected change of systems.

> In science as in life, it is well known that a chain of events can have a point of crisis that could magnify small changes. But chaos meant that such points were everywhere. They were pervasive. In systems like the weather, sensitive dependence on initial conditions was an inescapable consequence of the way small scales intertwined with large. (Gleick, 1987, p.23)

According to recent developments in physics associated with chaos and complexity, nature should be viewed in the form of creativity because we experience the emergence of structures that bear witness to the creativity of nature everywhere. The possibility of systems at the bifurcation point opens the window of opportunity for dissipative structures. Then, bifurcations can be considered the source of diversification and innovation. The wonder of nature always comes with unexpected surprises. The role of dissipative structures exposes the possible choices of system at far from equilibrium. With irreversibility of evolutionary process, the system will choose one of the possible branches in which we cannot determine beforehand. The chosen will emerge in a new form of order that derives from disorder, or in Prigogine's terms 'Order out of Chaos.'

In Prigogine's evolutionary process we see the deterministic temporary process at near equilibrium intertangle with the probabilistic process at far from equilibrium. This evolutionary process will evolve forwardly in this path involving a succession of bifurcations. We live in a pluralistic world in which chance and necessity, order and disorder coexist. For Prigogine, these conflicting views of nature can be reconciled in the evolutionary process in which irreversibility plays the important role and reversibility is exceptional cases. At first the term 'chaos' used to be apprehended as the 'unordered' which did not have any relationship to order at all. Now chaos is known in another sense as Weingart and Maasen say, "By the mid-nineteenth century this view had been replaced by two others, both now related to order (albeit in opposite ways). On one account, chaos became known as the opposite of order; on another account, as the source of order (Weingart & Maasen, 1997, p.480). Prigogine says:

> In many cases it is difficult to disentangle the meaning of words such as 'order' and 'chaos.' Is a tropical forest an ordered or a chaotic system? … Whatever the precise meaning we will eventually give to this terminology, it is clear

> that in some cases the succession of bifurcations forms an irreversible evolution where the determinism of characteristic frequencies produces an increasing randomness stemming from the multiplicity of those frequencies. (Prigogine & Stengers, 1984, p.169)

The diversity of species in a tropical forest, for Prigogine, can represent the archetype of order. And in his evolutionary process, chaos becomes the source of order. A new synthesis is emerging, and it is worth reflecting on his further remark: "It is quite remarkable that we are at a moment both of profound change in the scientific concept of nature and of the structure of human society as a result of the demographic explosion. As a result, there is a need for new relations between man and nature and between man and man" (Prigogine & Stengers, 1984, p.312).

Conclusion

Prigogine's perspective on nature should be considered the turning point for reestablishing our relation with nature and reconstructing an alienated world to be our home. Whereas Newtonian physics left us a world ruled by deterministic laws and having no place for novelty, quantum physics brought us to a world of pure chance, incomprehensible, or in Einstein's terms, a world ruled by a dice-playing God. They left us a narrow path to walk with tragic choices to choose. From the long history, we now start to see a new light on a new road that can lead us to a new understanding of the complexity of nature. Prigogine writes in *The End of Certainty*:

> What is now emerging is an 'intermediate' description that lies somewhere between the two alienating images of a deterministic world and an arbitrary world of pure chance. Physical laws lead to a new form of intelligibility as expressed by irreducible probabilistic representations. When associated with instability, whether on the microscopic or

> macroscopic level, the new laws of nature deal with the possibility of events, but do not reduce these events to deductible, predictable consequence. This delimitation of what can and cannot be predicted and controlled may well have satisfied Einstein's quest for intelligibility. (Prigogine, 1997, p.189)

We live neither in an arbitrary world of pure chance nor in a deterministic world without novelty and creativity. We actually live in the world of complexity where chance and determinism evolve continuously in the evolutionary process. Nature and humanity are interwoven creatively in this process. Life and nature, according to Prigogine, is never-ending process of evolution. We have not yet reached the end of the road, as in Hawking's expectation in his *A Brief History of Time* where we will be able to know the 'mind of God' (Hawking, 1988, p.175). On the contrary, our "real" dialogue with nature has just begun, and in this dialogue we have to both listen and speak. We nowadays seem to stand at the age of chaos and what will happen is unpredictable. The new perspective proposed by Prigogine needs our consideration. It may not be the final answer, so our dialogue with nature must carry on with our new wonders. Whitehead directed us with beautiful words, "Philosophy begins in wonder. And, at the end, when philosophic thought has done its best, the wonder remains" (Whitehead, 1938, p.168). Nature, therefore, is the source of all wonders. And our dialogue can represent in various forms of communication, e.g., scientific descriptions of scientists, deep insights of philosophers, beautiful poetry of poets, beautiful paintings of artists, etc. Then philosophers, scientists, artists, and ordinary people, should all participate in this dialogue. We all are interrelated in this universe. To be is to participate.

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