Open Systems Science: A Challenge to Open Systems Problems

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1 Introduction

Science and technology burgeoned in the sixteenth and seventeenth centuries. Quintessential examples of the achievements of this age are the physics and astronomy of Copernicus and Galileo, as well as Newton's physics and mathematics. The seventeenth century saw a modern scientific approach develop on a Cartesian basis. This methodology contributed enormously to scientific advances from the eighteenth century onwards, and to technological progress that accelerated in the nineteenth century. Thus, the methodology of modern science can be largely credited with the industrial prosperity and economic development that the world has achieved today. It has also advanced medicine and improved standards of living.

2 The Contribution of Descartes

For all this, we are greatly indebted to René Descartes, the father of modern science. In his famous book, "Discourse on the Method," published in 1637, Descartes proposed the scientific method consisting of four steps. Reflecting on these steps, he wrote

1. The first was to never accept anything as true which I could not accept as obviously true.
2. The second was to divide each of the problems I was examining in as many parts as I could, as many as should be necessary to solve them.

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3. The third was to develop my thoughts in order, beginning with the simplest and easiest to understand matters, in order to reach by degrees, little by little, to the most complex knowledge, and
4. The last was to make my enumerations so complete and my reviews so general that I could be assured that I had not omitted anything.

We can say without hesitation that modern sciences and technologies in its entirety have been built on a methodology comprising these four steps.

3 Drawbacks

Nonetheless, there are still plenty of complex issues that are hard to resolve. One such example is sustainability of the earth. This issue involves energy, climate, population, food, biodiversity, poverty and inequality, safety assurance, and many other mutually dependent factors that cannot be solved independently from one another.

Another example is the matter of life and health. Although medical science has settled almost every issue, there remain diseases such as cancer, metabolic disorder, and immunodeficiency that develop only through the interrelation of complex factors.

Yet another category of examples concerns instability in the global economy, and safety in food and huge social infrastructures, all of which consist of networks of people, materials, and information. Although constituting elements and network topologies are changing every day, our expectation is that—even in the event of unforeseen incidents—they will continue to deliver services without causing any critical impact on everyday life.

These challenges that we wish to address seem to have two common characteristics. The first is that all of these challenges are related to the problem resolution of integrated systems comprising numerous ever-changing, interrelated subsystems. In many cases, we cannot even identify the boundaries of the systems we are examining, what subsystems are involved, and how they interact in the problem systems.

The second characteristic is that these challenges require that we somehow predict the future and take action even though we know that our prediction is imperfect. In other words, these challenges are not reproducible in reality as we cannot stop or reverse the systems in order to retry—a fact that we are reminded of by earth sustainability, life and health, and safety.

The question, therefore, is how can we really solve these issues? Through segmentation into specialized field, science has given us an extremely precise understanding of fundamental principles. With its help, many challenges have now been resolved, but these were static in nature or both regular and reproducible. In the case of challenges with dynamic, intricately interrelated factors, and non-reproducible events, the steps of separation into specialized fields and reconstitution cannot be applied in the same way as before.

More than a few philosophers have reflected on the limits of Cartesian-style reductionism. Karl Popper [1], for example, considered "falsifiability" is the base for science. He held that a scientific theory is valid until it is falsified and replaced by a new theory. Thomas Kuhn [2], meanwhile, pointed to the "paradigm shifts" in that normal state and revolutionary state occurs in the development of science.

Certain scientists have proposed a new perspective of the "system." For example, in the years leading up to the 1960s, Bertalanffy proposed General System Theory [3] and Ilya Prigogine and his collaborators proposed the concept of dissipative systems [4]; Francisco Varela and his colleagues proposed the notion of autopoiesis [5] in the 1970s. Yet, none of these led to a specific methodology that could replace the conventional reductionism. Eventually, I came to believe that we were in need of a new scientific method to address "open systems"—systems that interact with the world outside and that include elements which themselves interact in an intricate fashion and that change over time.

4 Open Systems

As the name suggests, open systems are the opposite of closed systems. A closed system is a system that has no interaction at all, or a fixed interaction with the outside world. This type of system may consist recursively of closed subsystems. A closed system can be characterized as having its boundary, structure, and functions fixed. A closed-system problem is a problem that resides in a closed system.

An open system, on the other hand, is a system that interacts with the outside world, similar to what Bertalanffy defined in his General System Theory, so that it can change its boundary, internal structure, and functions over time. An open system can consist recursively of open subsystems. An Open System Problem is a problem that resides in an open system (see Fig. 1).

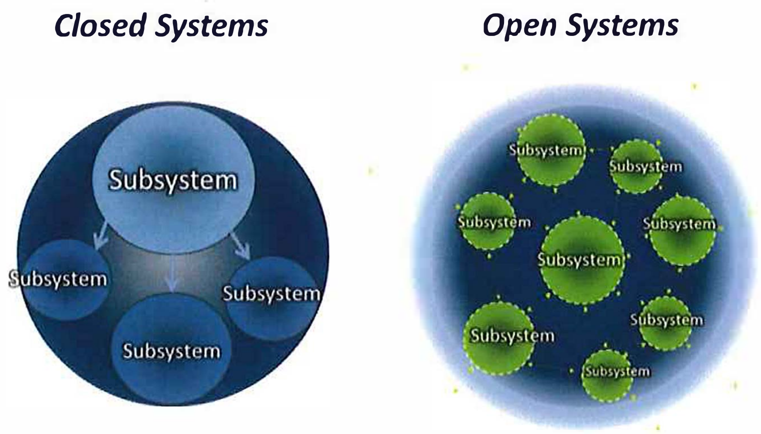

Fig. 1 Closed systems vs. open systems

Table 1 Characteristics of closed and open systems

Closed systems		Open systems
Fixed and definable	Boundary	Indefinable
Fixed	Function	Change in time
Fixed	Structure	Change in time
Equilibrium	Nature	Temporal development
Yes	Reversible	No
Yes	Reproducible	No
Yes	Divisible	No
External observer	Viewpoint	Internal observer

In reality, everything interacts with the outer world, even though it doesn't look like. Nevertheless, there are many problems that are simple in nature, meaning that they can be treated as closed-system problems, and therefore, reductionism works perfectly with the corresponding problems. However, it is not always true, especially in regard to those issues that we face in the twenty-first century. Table 1 shows a comparison of the characteristics of closed systems and open systems.

5 Open Systems Science

I wondered whether we could actually solve an Open System Problem. It appeared to be impossible in the sense that we could give a strong, complete solution to a closed system. However, it did appear to be possible from the perspective of supplying a means to make the entire situation better, not worse, through our best effort. Confident in this belief, I proposed Open Systems Science [6, 7] as an approach to solving the problems of open systems.

The method can be described as follows:

1. Provisionally define the system in which the problem is considered to reside.
2. Model the problem in the system.
3. Investigate whether the behavior of the model over time is self-consistent and consistent with the actual system's behavior.
4. If not, (a) revise the model and (b) if necessary, redefine the problem system, and remodel the problem.
5. Repeat until a satisfactory result is obtained.

Please also see Fig. 2.

As may be clear, Step 1 to Step 4(a) as corresponding to reductionism. A small but important new addition is Step 4(b), and this is the characteristic feature of Open Systems Science. In reductionism, subdivision of a given system into subsystems is performed to precisely understand the problem system in detail. In Open Systems Science, however, more emphasis is placed on identifying the problem system in relation to other systems, and understanding relationships among its subsystems

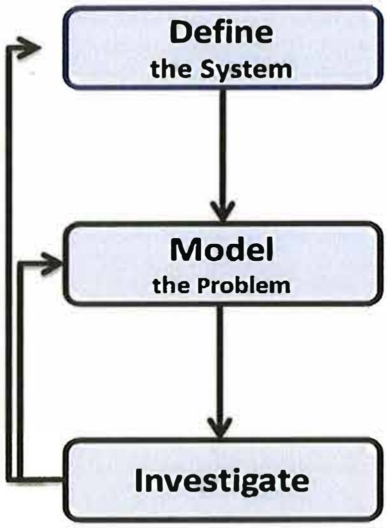

Fig. 2 Methodology of Open Systems Science

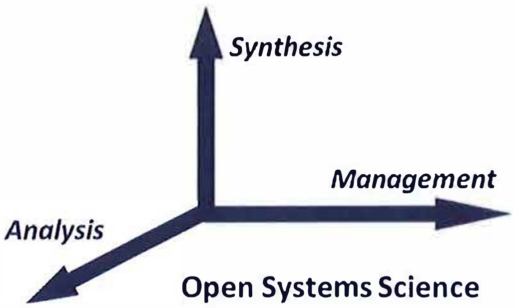

Fig. 3 Three perspectives of Open Systems Science

to ascertain a system's true nature. Digging deep into each subsystem while also mapping how they are interconnected leads to a better understanding of each problem, and therefore, to better solutions.

Another important point is that Open Systems Science introduces the new perspective of "management" into science, thereby augmenting the perspectives of "analysis" and "synthesis" that are provided by reductionism (see Fig. 3). It explores the most appropriate problem system so that the degree of contradiction or divergence from the actual system's behavior does not exceed acceptable levels. Such levels are determined initially by researchers, but a consensus must ultimately be reached by stakeholders and society. Such a consensus is not made on the basis of whether the solutions are true or false, but whether they are acceptable or not for each stakeholder, based on sufficient evidence to assure, with various trade-offs, including cost, also taken into consideration. Hence, this is not a matter of truth (or understanding the principle) but value (finding a solution), and as such, it exists in the domain of management.

Using this framework, we can predict our future in an explainable way. And the accuracy of this future prediction can be gradually improved. Of course, we can also examine and understand past events better.

6 A Few Examples

This methodology of Open Systems Science has been put to practical use in various research projects. It is the fruit of long and diverse discussions with researchers at Sony Computer Science Laboratories [8] and others through the investigation of various concrete research topics.

Systems biology [9] is a new method of biological study established by Hiroaki Kitano. He has shed fresh light on the essence of life by defining it in terms of the management of huge functional networks called pathway networks. Based on this, Kitano and his collaborators proposed long-tail drugs and personalized medication [10]. Systems biology is being extended by Kazuhiro Sakurada, from the viewpoint of historicity. Sakurada took internal, irreversible structural changes caused by an individual's development into consideration. This has provided another base for personalized medication [11, 12].

Masatoshi Funabashi has proposed a new system of agriculture called synecoculture [13]. Based on symbiotic associations of edible species, this system allows the natural environment to be powerfully recovered and reconstructed under any climate conditions where plants can grow. Kaoru Yoshida has integrated molecular biology with healthcare, food, and agriculture to form a new field of food science [14, 15]. Takahiro Sasaki is investigating the co-evolution of influenza viruses and human society, by incorporating multiple factors such as infection mechanisms, carrier animals, geology, climate, and social systems, all interrelated on diverse scales along temporal and spatial axes [16].

One final example is the DEOS project in which we aim to ensure the dependability of massive, man-made, continually changing systems. For such a system, we defined Open Systems Dependability [17]. We have shown that an iterative improvement process, called the DEOS process, with its embedding architecture can achieve Open Systems Dependability.

7 Discussion

Science as it has historically been practiced—adopting a reductionist standpoint in the pursuit of pure research and disconnected from society—represents a tacit license for scientists to be indifferent to the potential applications of their discoveries. This way of thinking has long been the touchstone of science. Great value has been placed on pure research, thereby stoking relentless competition among researchers to lay claim to advances.

Table 2 Properties of reductionism vs. Open Systems Science

Reductionism		Open Systems Science
Equilibrium systems	Object	Temporal development systems
Understanding principles	Purpose	Making consensus
Decomposition	Means	Identification of problem systems
Inward	Direction	Outward
In vitro	Treatment	In vivo
Strong/Perfect	Outcome	Action for the better
Observer	Subject	Actor
Indifferent	Consequence	Responsible
Justice	Value system	Humanity
Profession	Attitude	Citizen

However, in reality, the challenges we need to address—such as those suggested by the global agenda—are all woven into the fabric of society. These issues are products of vast, irreducible, interconnected systems, and feature a bewildering diversity of stakeholders. As such, solutions devised for sub-problems in isolation from the overall system routinely fail to address the broader scope of the issues they seek to resolve. Proposals to address such challenges must win the approval of diverse stakeholders, and achieve a social consensus. This is the point at which scientists, as researchers and as experts, can no longer act as external observers: they must become actors. And this is where Open Systems Science comes into its own, by defining scientists not as people of narrow expertise, but as fully rounded individuals with the capacity to make holistic value judgments, while accepting responsibility for the outcomes and applications of their research and acting selflessly to accelerate the formation of a consensus.

In such situations, it must be recognized that there is often no single correct solution; and furthermore, that decisions made at a given point in time can prove in retrospect to be mistaken. Stakeholders, accordingly, must work toward a consensus about the solution to a given problem, with science providing both the methodology and evidence for achieving that end.

Table 2 shows a comparison of how I see the properties of reductionism and Open Systems Science. I would greatly appreciate your comments and suggestions.

8 Conclusion

In this paper, I suggested that current challenges needing to be addressed urgently are mostly Open System Problems. As an appropriate methodology to address Open System Problems, I proposed Open Systems Science and gave the definition of that method. In Open Systems Science, a new perspective of management becomes important in addition to the conventional perspectives of analysis and synthesis, since we need to achieve consensus among stakeholders. I showed some examples of the methodology being applied in establishing new areas of research. Finally, I extended my perspective toward the future of science.

My path to this new scientific methodology was first made clear in an address in 2008 at the Sony CSL Symposium. The content of that address later appeared in a book [6] but my thinking was still embryonic. I then gave a few lectures and wrote an article [7] as my thinking became clearer. And I hope this current paper presents Open Systems Science in a concrete and understandable way.

Open System Science is a scientific methodology suited to the modern day in the sense that we can fully utilize high performance computers, databases, and the Internet to solve complex problems. I believe that Open Systems Science can be applicable to a wide range of real problems that must be addressed for the sake of this and future generations, and my greatest wish is that it can contribute to the progress of humanity and peace in our world.

About the Author

Dr. Mario Tokoro is Founder and Executive Advisor of Sony Computer Science Laboratories, Inc., Japan. He is a former Professor of Computer Science at Keio University and a former Senior Vice President and Chief Technology Officer of Sony Corporation. In 1988, he established Sony Computer Science Laboratories, Inc. He served as Director of Research, President and CEO, and later as Chairman and CEO. He is an expert in Computer Science and Engineering, Philosophy of Science and Technology, and Research Management. He is currently leading Sony CSL's Open Energy Systems initiative.

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