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Why Complexity?

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Opinion

Leonardo da Vinci (1452-1519) was a great painter, sculptor, architect, mathematician, scientist, inventor, engineer, musician, writer, astronomer, historian, etc. He even found time and energy to fight the tax authorities. He was a Renaissance man, a polyhistor, a polymath, i.e., a person whose expertise spans a significant number of different subject areas. He was not alone: Michelangelo (1475-1564), Galileo (1564-1642), Isaac Newton (1643-1727), Gottfried Leibniz (1646-1716), Benjamin Franklin (1706–1790), Mikhail Vasilyevich Lomonosov (1711-1765), Thomas Jefferson (1743-1826), Winston Churchill (1874-1965), Albert Schweitzer (1875-1965) and many others were knowledgeable in many different fields.

It is difficult to find such people today. The great discoveries of the 19th and 20th centuries led to an enormous increase in the number of scientists and more and more specialization. Ninety percent of all the scientists who ever lived is alive today and almost all of them are working in narrowly specialized fields. It is enough to take a look at the first and last Nobel prizes in Physics. The first prizes were awarded for the discovery of X-rays and radioactivity, the 2015 prize for the discovery of neutrino oscillations. The specialization was inevitable but led to the worrisome fragmentation of sciences and even to the split between two cultures – the arts and humanities on one hand and the "hard" sciences on the other. The common culture of humankind has gradually disappeared (see C.P. Snow: *The Two Cultures*, 1959).

It was eventually recognized that we needed a holistic approach to understand the world around us: we are concerned with "wholes" (complete systems) rather than their dissection into parts. Moreover, it was also recognized that the whole is much more than and very different from the sum of its parts (P. W. Anderson, More is different, Science177, 4047, pp. 393-396, 1972).

This is the opposite of *reductionism*, which attempts explanation of entire systems in terms of their individual, constituent parts. *Reductionism* derives everything from physics. But physics is not a monopolistic way of knowledge.

Indeed, if everything obeys the same fundamental laws, then the only scientists who are studying anything really fundamental are those who are working on those laws: astrophysicists, elementary particle physicists, logicians and some mathematicians. However, at each level entirely new properties appear. Psychology is more than applied biology and biology is more than applied chemistry. Large systems undergo phase transitions: certain properties suddenly change (e.g., solid, liquid, and gaseous phases of matter) and basically new types of behavior emerge. This was first recognized by Karl Marx who said that quantitative differences may become qualitative ones.

The Santa Fe Institute was started in 1984 with the purpose of studying interdisciplinary subjects with the holistic approach. In 1987, two Nobel Prize winners, economist Kenneth Arrow and physicist Philip Anderson brought together ten economists and ten scientists for a now-famous conference at the Institute. The purpose was to see how economics could benefit from physics, computer science, and biology. I believe this meeting was the beginning of modern Complexity Science. An enormous amount of work has been done since. A large number of books have been written. Complexity Science has become "the umbrella Science, the Science of Sciences," "the most important scientific development since General Relativity," "the science of interest for future generations."

Complexity is not amenable to traditional methods of science. According to Heinz Pagels, "The nations who master the new science of Complexity will become the economic, cultural, and political superpowers of the 21st Century." Stephen Hawking's advice for graduate students: *"Embrace complexity. The 21st century will be the Century of Complexity."*

So, what is Complexity? What are the key issues associated with Complexity? What are the main approaches to study Complexity? What are the ways of describing complex systems? What are the processes of formation of complex systems? How local interactions give rise to global patterns of behavior? What are the emergent phenomena? What is chaos? What are fractals? What is the Mandelbrot set? How swarms behave? What are the analytical and computational tools for studying Complexity? What is the role of cellular automata and N-person games in Complexity Science? What are the main application areas of Complexity?

All these questions and much more are explained in the author's new book Complexity: A Primer available at amazon.com.