Introducing Complexity Science in Higher Education for Preparing the New Generations to be Aware and Promote a Sustainable Future.

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Abstract

The presence of almost 8 billion humans on Earth and their interconnections promoted by the pervasive Information and Communication Technologies and the fast means of transport make humanity a strongly intertwined network. A problem in a community or a sector regards directly or indirectly everyone on Earth. Any local accident or issue can have global repercussions. Therefore, we are called to face challenges, which are global. It is compelling to prepare new generations to tackle such global challenges. A paradigm shift in higher education is required. It is urgent to train not only specialists but also generalists (also said polymath or hybrid figures). This work proposes a strategy to prepare generalists. It is based on interdisciplinary Complexity Science. The features shared by all those Complex Systems that are involved in the global challenges, i.e., living beings, ecosystems, urban areas, world economy, and human societies, must be evidenced and understood through specific scientific theories. Furthermore, the difficulties in describing and predicting the behavior of Complex Systems should be taught. The fundamental thinking skills that next generalists should have for problem-solving are discussed. Generalists are called to integrate the economic, societal, environmental, and ethical dimensions for fully sustainable development.

Keywords: *Higher Education; Interdisciplinary; Global Challenges; Complex Systems; Systems Thinking; Natural Computing.*

1. Introduction

The development of means of transport and information and communication technologies has been transforming humanity radically. Humans are now more linked to each other than ever before. Humanity as a whole is a vast and very dynamic network on Earth. Every node of this huge network, i.e., every person, has personal problems to solve. The almost 8 billion people worldwide have practically 8 billion agendas for reaching their psychophysical wellbeing. However, every human belonging to the humanity-network also needs to face challenges regarding the network as a whole. Such challenges are global for two reasons. First, they might regard almost everyone on Earth. Second, they might be multi-sectorial because they encompass humanity under different points of view, such as health, social, political, cultural, ethical, and economical. Global challenges require global agendas to be faced and won. For instance, in 2015, the United Nations have compiled a comprehensive and far-reaching agenda (i.e., the 2030 Agenda) that included 17 goals assuring a general sustainable development if pursued worldwide [1]. At the heart of all the global challenges, there are human beings, their societies and the world economy, the urban areas, the natural ecosystems and all the living beings they embed, and the climate. They are Complex Systems [2]. Seemingly, they are diverse and traditionally investigated by well-distinct disciplines, such as Medicine, Biology, Psychology, Social Sciences, Economy, Ecology, Engineering, Physics, Chemistry, et cetera. Such subjects are often maintained well-distinct and taught separately at the Universities, apart from a few exceptions.

The consequence of monodisciplinary teaching is that we prepare specialists who are not endowed with the required knowledge and skills to face the global challenges of this century. In our opinion, we need to form not only specialists but also other professional figures who have in mind the concepts and methodologies required to propose solutions to the global challenges. Such figures, called either polymath [3] or generalist [4] or hybrid [5], should be formed by teaching them Complexity

Science, according to our vision. With Complexity Science, we refer to the interdisciplinary domain of research on Complex Systems that emerged in the 1980s [6] and is still *in fieri*. This contribution aims to propose an education path to form polymaths. In paragraph 2, the scientific theories relevant to understanding Complex Systems from an ontological point of view are presented. In paragraph 3, the limitations science encounters in describing Complex Systems are evidenced. Finally, the fundamental thinking skills to face global challenges are mentioned in paragraph 4.

2. The Features of Complex Systems

Complex Systems such as all the living beings, their societies, ecosystems, and the climate appear to be very different. However, they share some relevant features outlined by Complexity Science.

First, all the Complex Systems can be described as networks [7-9] with nodes and links as the main elements (see Figure 1). Different Complex Systems have distinct networks' architectures. Nodes and links are often diverse and even variable in their behaviour.

Second, Complex Systems are out-of-equilibrium in the thermodynamic sense [2, 9]. They constantly dissipate energy and matter by producing entropy.

Third, Complex Systems exhibit emergent properties, such as the power of self-organizing in time and space, chaos, adaptation, resilience, et cetera [8, 9].

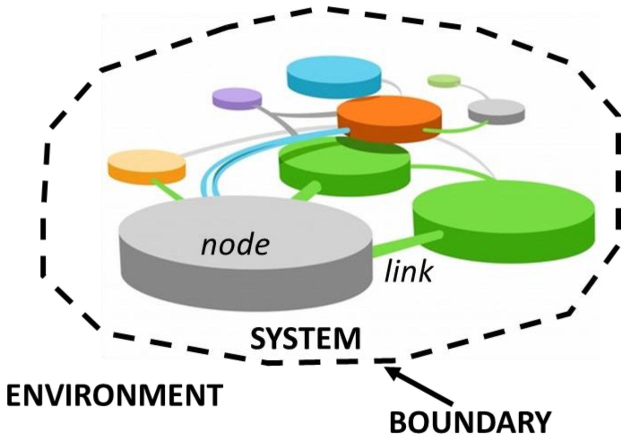

Fig.1. Complex Systems are networks in out-of-equilibrium conditions and show emergent properties [2, 8, 9].

Network Science, Out-of-equilibrium Thermodynamics, and Non-linear dynamics are basic theories to prepare the next generations of polymaths. Such theories must be taught using an interdisciplinary approach, i.e., by proposing examples drawn from distinct disciplines.

3. Complexity from an epistemological point of view

A fundamental contribution to the formation of polymaths derives from teaching them the hurdles humans encounter in describing and predicting the behaviour of Complex Systems (Figure 2).

Specific emergent properties of Complex Systems are not understood yet. The reason is due to two kinds of epistemological complexities, which are known as "Descriptive Complexity" and "Computational Complexity" [2, 9].

"Descriptive Complexity" refers to the difficulties we encounter in describing Complex Systems through the reductionist approach because it is necessary to specify:

1. The number of nodes, their diversity, and behaviours' variability.
2. The number of links, their diversity, and variability.
3. The sensitivity of all these features to the context.

In social science, not all the links are measurable in quantitative terms. Moreover, their analysis might perturb the links. The observer becomes a network's node, particularly in sociology [10].

"Computational Complexity" refers to the existence of many intractable computational problems. In other words, there are computational problems regarding Complex Systems, which cannot be solved accurately and in a reasonable lapse of time even if the most powerful supercomputers are at our disposal. For such problems, well-known as NP-problems, only approximate solutions are achievable.

Even if we could expect that, one day in the future, these two kinds of epistemological complexities would be untangled, the predictive power of science would maintain two intrinsic limitations [2, 9]. One limit is related to the description of the microscopic world, which is expressed by the Heisenberg Uncertainty principle. The other one regards any chaotic dynamic, which are aperiodic, extremely sensitive to the initial conditions, and unpredictable in the long term by definition because the initial conditions of any system cannot be determined with infinite accuracy. Still, unavoidable errors and uncertainties always taint the determination of the initial conditions.

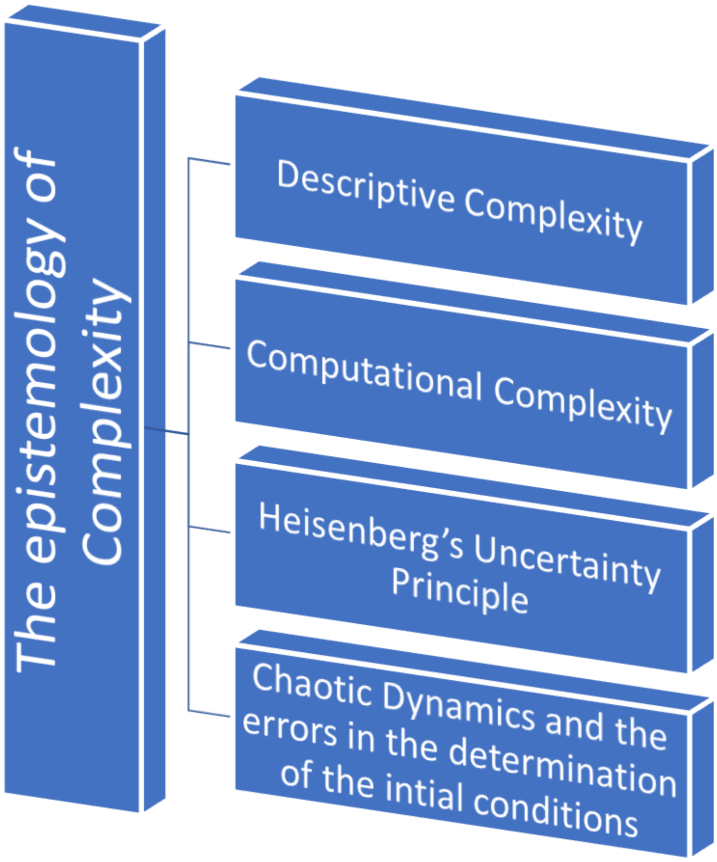

Fig. 2. The elements contributing to Complexity from the epistemological point of view.

4. Thinking Skills to Promote Sustainability

Polymaths should be capable of living or inhabiting Complexity to ensure a sustainable future [5]. Such capability requires some creative thinking skills that make the polymath apt to problem-solving [11]. The thinking skills we consider fundamental are listed below.

1. A polymath figure has necessarily interdisciplinary interests and knowledge.
2. Systems thinking should be taught along with the reductionist approach. Cognitive Maps, Systems Thinking Concept Map Extension (SOCME), and Geographical Information System (GIS) aid in exploring, understanding, and depicting both within-systems and cross-system interactions and in managing complex scenarios [12]. Another valuable way for implementing Systems Thinking is through Service-learning. Service-learning is a teaching strategy that intentionally engages students into communities through service activities. This approach has been tested in many areas. For instance, to design urban green areas [13].
3. A non-linear mindset should be forged through computer simulations and agent-based modeling in addition to a centralized and "clockwork" mindset. Clockwork mindsets favor reductive understandings, centralized control, and linear cause-and-effect relationships [14]. On the other hand, non-linear mindsets, based on positive and negative feedback actions, understand emergent phenomena and decentralized control.
4. An algorithmic thinking should also be trained through Natural Computing [9, 15], whose rationale is that any distinguishable state of either matter or energy can be used to encode information, and any of its transformations can be conceived as computations. Based on this idea, any Complex System can be analyzed through a three-steps procedure. The first step is the computational level analysis, which determines the inputs, outputs, and computation the

system performs. The second step is the algorithmic analysis, which consists of formulating an algorithm that can perform the previous computations. The final step is the implementation level analysis that searches for mechanisms that implement the formulated algorithm. If the three-level analyses are carried out appropriately, the final mechanisms will be plausible replications of the Complex Systems' behaviors. Such replicas will be reasonable models for interpreting Complex Systems.

5. It is usually stated that sustainable development has three dimensions: economic, societal, and environmental. An ethical extra-dimension must be added. Polymath figures must be formed technically and ethically to build an equitable future. The awareness of the limitations humanity encounters in describing and predicting the behaviour of Complex Systems makes all those technologies that perturb and modify the spontaneous evolution of Complex Systems highly disputable. Any polymath should always be prompt to raise a fundamental question: "Is it always fair to do what technologies make doable?". The answer should be found by interrogating not only science but also other forms of knowledge.

5. Conclusions

For a sustainable future, it is compelling to form polymaths who can face global challenges. The theories and thinking skills we consider fundamental have been discussed. They are summarized in Figure 3, below.

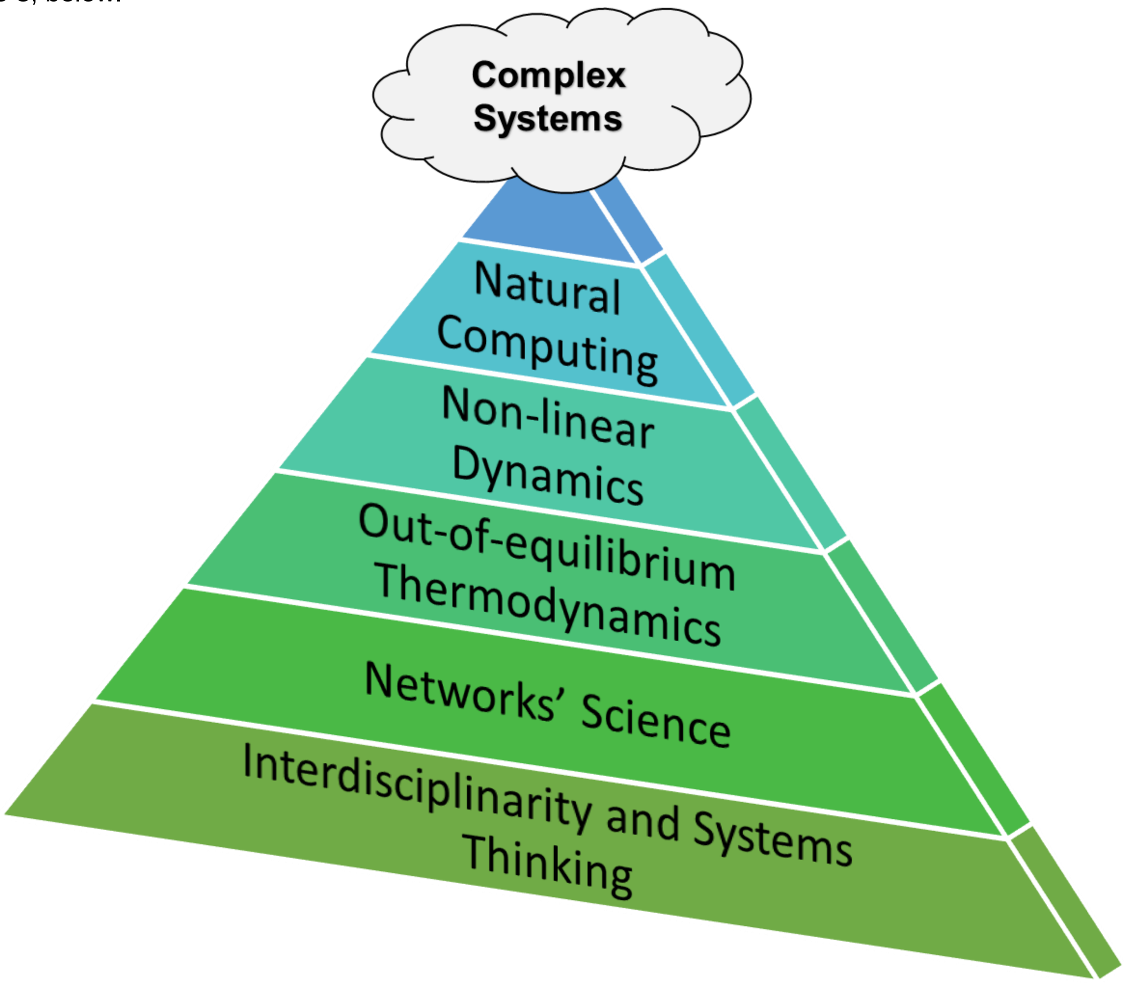

Fig. 3. Fundamental thinking skills and theories to prepare polymaths to promote a sustainable future.

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