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CoSy Thinking

REPORT ON LITERATURE REVIEW ON THE THEORY OF COMPLEX SYSTEMS APPLIED TO:

CHEMISTRY AND BIOLOGY

SOCIOLOGY AND PHILOSOPHY

LANDSCAPE PLANNING AND DESIGN

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ABSTRACT

The global challenges characterizing the XXI century require a paradigm shift in research and education. All the global challenges regard Complex Systems. Complexity Science needs a definitive formulation. Such formulation will break down the traditional disciplinary boundaries. Although Complexity Science has not reached its final formulation yet, it is compelling to teach the interdisciplinary subject of Complex Systems to the new generations. In this contribution, (1) we highlight the common features of the Complex Systems involved into the global challenges that humanity is spurred to face; (2) we show the relevance of Complexity Science to promote sustainability; (3) we suggest cross-disciplinary contents and methods for teachers, students, and employers.

1. Introduction

Some of the past century's fundamental scientific advances—nuclear energy, artificial fertilizers, or vaccines—came from the domain of a single discipline: physics, chemistry, or biology [1].. As the 21st century unfolds, it is increasingly clear that the pressing problems in energy, food, climate, ecology, geology, health, economy, and sociology will not be solved in the same way. The United Nations have compiled the 2030 Agenda [2] to stimulate action in these areas of critical importance for humanity and the Earth. Reaching the goals and targets included in the 2030 Agenda requires dealing with Complex Systems [3]. The investigation of Complex Systems needs close cooperation among all the scientific branches and between science and the humanities. Such collaboration should promote the development of Complexity Science. There is great expectation from the Complexity Science because it should help humanity face complex crises such as the current Covid-19 pandemic [4] and make the best choices in situations where psychophysical health, economic, and social aspects are all tightly intertwined.

2. Results Achieved

2.1 Complexity Science

The goals and targets of the 2030 Agenda can be reached if Complexity Science focuses on the following Complex Systems:

- Human beings and their psychophysical well-being;
- Human societies;
- World economy (primary, secondary, tertiary, and quaternary sectors);
- Ecosystems, urban green systems, and all the living creatures that are within;
- Climate.

Such systems are investigated by well distinct disciplines. An authentic interdisciplinary dialogue among scientists specialized in different sectors should allow to pinpoint all those characteristics that are shared by Complex Systems. Based on our personal experience and our collaboration, we have found that Complex Systems share the features described below.

a) Any Complex System can be described as a network with nodes and links (or edges). Different Complex Systems have distinct architectures [5]. In general, the degree of complexity depends on the number of nodes (multiplicity of the network) and the number of links (interconnection); the diversity of nodes and links; the variability of the behavior of the single nodes and hence their links [3]. Social networks are the most complex because the interactions among people (i.e., the nodes) can be established and maintained very far in space and time [6]. The most recent innovations in Information and Communication Technologies affect so strongly the number, types, diversity, and variability of the relationships that some decades ago was unimaginable. Such unrelentless innovations has favored a transition of the human societies from complexity to hyper-complexity [6].

b) Complex Systems are out-of-equilibrium systems, in thermodynamic sense [5]

c) Complex Systems exhibit emergent properties [3]. One of the most astonishing examples of emergent property is life. Life cannot be attributed to the single chemical components that are present in every living being, such as DNAs, RNAs, proteins, phospholipids, water, ATP, et cetera. Life emerges only when we consider all the characteristic compounds of every living being organized in that peculiar spatiotemporal

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architecture that is a cell [7]. Other examples of emergent properties are the phenomena of self-organization, chaotic dynamics, adaptability to environmental changes, and resilience [8]. If we observe social organization or simply a group of people or even a random set of people merged together, not only will the totality be superior to the total number of people, not only will we be unable to understand the dynamics of the group by isolating individuals or narrowing our fields of observation, but we will be forced to realize that these same people (individuals, entities) are constantly modifying, co-creating, co-constructing the social environment in which they are immersed [9]. A community-based approach in Urban Green Systems management within any city helps in self-organization. Placemaking develops the human society energies of creativity [10]; urban agriculture is a catalyst for unpredictability by allowing space for unplanned and unstructured initiatives [11]; sportspeople like to define new ways for using services or track new trails [12]. Spaces for self-organization are not in contrast with traditional urban plans, but they outline a complexity-respecting form of the planning process where expert and empirical knowledge can easily be integrated [10]. In this manner, society's growth co-evolves with the systems by which it is fed. Anyway, self-organizing processes require patience and a plan able to give trust to the local community and nature [13]. Biel [11], using urban agriculture, outlines a future where society re-energizes itself, in the sense both of recapturing creative dynamism and of applying creativity to meeting physical energy needs. Both require us to embrace self-organizing properties, whether in nature or society. Food provides the energy for people to function, but at the same time, acts as a catalyst for the development of human society's energies of creativity and self-organization.

d) Any Complex System cannot be described exhaustively, and the behavior of any Complex System cannot be predicted exactly. The predictive limitations are particularly strong in the long term. These limitations are due to three principal reasons [5, 3].
    1) The first reason is linked to Computational Complexity: many computational problems regarding Complex Systems are Non-Deterministic Polynomial (NP) problems. NP problems having large dimensions are solvable but intractable. In other words, we cannot determine the exact solution even if we use the fastest supercomputer in the world.
    2) The second reason is that Complex Systems exhibit variable patterns. Variable patterns are entities or events whose recognition is made difficult by their multiple features and their extreme sensitivity on the context. There are not universally valid and effective algorithms for recognizing variable patterns. This difficulty generates what we call Descriptive Complexity [3]. In social science, not all interactions are measurable in quantitative terms. The qualitative method is required. The objects or patterns observed, other than being modified by the act of being observed, also interact with the observer. Thus, the observer not only modifies the "objects" observed, but is also himself modified. In sociology, the observer is often termed "observer/participant" [9]
    3) The third reason is that the predictive power of science has intrinsic limitations. These limitations regard the dynamics of microscopic particles and the chaotic dynamics. As far as the microscopic world is concerned, the Heisenberg Uncertainty Principle holds. It declares the impossibility of determining simultaneously and accurately pairs of variables, such as position and momentum of a particle. Therefore, it is not possible to make reliable predictions of particles' dynamics. Finally, any chaotic dynamic is aperiodic and extremely sensitive to the initial conditions. Since the determination of any initial condition is always affected by unavoidable errors and uncertainties, it derives that any chaotic dynamic is unpredictable in the long term, by definition [3, 5].

2.2 Sustainable development

Sustainable development requires both reductionist and systemic approach [14]. Reductionism focuses on details at smaller and smaller scales, while systemic or holistic approach emphasizes global behaviors. According to Li [15], it is also fundamental to ponder the scale that is intermediate between the element scale (analyzed by the reductionist approach) and the system scale (analyzed by the holistic approach), which is the mesoscale.

Sustainability can be fulfilled by a properly planned combination of interconnected actions that make any productive activity a tail of a mosaic wherein wastes are negligible or, even better, completely absent. For a sustainable world, economy must transform from linear to circular [5]. Given that the primary activities of chemistry are to analyze, synthesize, and transform matter, the practice of chemistry has a great deal to contribute to sustainability, which in turn should play an increasingly important role in reshaping the practice of chemistry [16].

The profession of chemistry must respond to its role in achieving sustainability agendas in a variety of ways, such as by:

- Contributing to the development of Complexity Science [17];
- Teaching Environmental Chemistry as a multidisciplinary subject [16];
- Spreading Green Chemistry principles and practices [16];
- Applying life cycle assessment (LCA). LCA considers all steps from the acquisition of raw materials to the disposal or recycling of waste- and end-products. It brings together green chemistry approaches and knowledge of toxicology, environmental dispersal, and degradation routes, and ecology of the relevant surroundings, creating an overall picture of the likely energy and material inputs and environmental releases, facilitating comparison of alternatives for products and processes [16].
- By developing the concept of “one-world chemistry”. This seeks to reposition chemistry as a sustainability science for the benefit of society, recognizing that the health of human beings, animals, and the environment are interconnected and require the adoption of systems thinking and cross-disciplinary working [16].

Sustainability issues must also be taken into account in the urban planning. If properly designed, Urban Green Systems can play relevant actions in a city because they affect the citizens’ quality of life [10]. Urban areas must be treated as if they were natural ecosystems, i.e., truly Complex Systems. Therefore, both the reductionist and the systemic approaches are needed. Comprehensive strategies for designing or managing complex social-ecological systems must address multiple scales and multiple system dimensions. Strategic planning and design of green infrastructure in cities can be a means of achieving this integration [18].

2.3 Inter-disciplinarity and trans-disciplinarity

Complexity Science grounds on multi-disciplinarity; it requires inter-disciplinarity, and it targets trans-disciplinarity [3]. When a Complex System is described by many distinct disciplines, then a multidisciplinary, fragmented, and polyhedric picture is generated. When specialists of different disciplines discuss and pinpoint the methods and models they share, a disciplinary network is formed, and a more organic description of the Complex System emerges through interdisciplinarity. The final goal is transdisciplinarity, which will be achieved when the Complexity Science will formulate a uniform description of any Complex System, breaking down the traditional disciplinary boundaries.

At the University College of London, the Arts and Sciences BASc Curriculum has been implemented. It shares some commonality with related curricula in liberal arts institutions in the US and elsewhere. Study time for each student is spent 50% on the Core of the degree and 50% on what are called Pathways. The Core is where the more radical inter-, post- and non-disciplinary modules are housed and the Pathways are selections of broadly cognate, more standard academic disciplines. In the Core, the frames need to be built. The frames are mental structures that shape the way we see the world. They are part of the cognitive unconscious of each of us, ‘structures in our brains that we cannot consciously access but know by their consequences [i.e., the effect these structures have on our assumptions and actions]. Compulsory first-year Core courses play an important role in the success of the program. Gombrich believes that these modules frame the program in such a way as to provide intellectual, cognitive, and moral support [19].

Interdisciplinary education should contain both arts and sciences and, in addition, look for syntheses and integration across the disciplines. The usual perception is: single discipline = specialism = good; interdisciplinary degree = fuzzy/vague = bad. This perception must be changed into: monodisciplinary degree = only a part of an interdisciplinary degree = inferior; interdisciplinary degree = more complete/fuller = superior [19].

Students attending interdisciplinary courses can focus simply on what they are interested in and which problems they would like to engage with, rather than worrying about which discipline they belong to. This approach to learning brings them in line with no less a figure than Karl Popper: ‘We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline. These interdisciplinary courses should change most universities, which are ruled by departments [19].

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Regarding the urban system, the big problem is that our knowledge has been segmented into discrete and often too strongly disconnected disciplines, and urban planners think layer by layer, searching for solutions for separated thematic points of view [20]). The Urban Green Systems have living and non-living components that usually are involved in complex relationships between resources and social and managerial conditions [21]. Innovative approaches need multidisciplinary solutions and interdisciplinary dialogue for evaluating synergy, relationships, conflict, and complementarity [13].. Tress and Tress [22] declares that landscape planning requires a transdisciplinary approach. They provide an overview of the transdisciplinary landscape concept. It is based on five dimensions of landscapes: (1) the spatial dimension; (2) the mental dimension; (3) the temporal dimension; (4) the nexus of nature and culture, and (5) the systemic properties of landscapes. In contrast to other approaches, Tress and Tress unite dimensions that are usually the domain of individual disciplines and make it possible to capitalize on landscape research plurality.

Below, we report a list of subjects that we consider fundamental for teaching Complexity Science [17, 3, 5]:

1) Out-of-equilibrium Thermodynamics because all Complex Systems are Dissipative Structures: they maintain order within them by dissipating energy and releasing entropy in the surrounding environment. Thermodynamics is a systemic theory and entropy is a cross-disciplinary concept. Thermodynamics is the only scientific theory which entails history.
2) Non-linear dynamics because all Complex Systems work in non-linear regime. They can give rise to either stationary or periodic or chaotic dynamics.
3) Networks' science because all Complex Systems can be described as networks.
4) Natural Computing is an interdisciplinary research line that proposes and looks for new algorithms, new materials and architectures to compute and face Computational and Descriptive Complexities, and new methodologies and models to interpret Natural Complexity (i.e., Complex Systems). The rationale is that any distinguishable physicochemical state of matter and energy can be used to encode information; every natural transformation is a kind of computation. Within Natural Computing, two research programs are prominent.
   A) In the first program, scientists mimic the features and the performances of the natural information systems, i.e., all those living systems that exploit matter and energy to encode, collect, store, process, and send information. The natural information systems to imitate are the living cells (also said Biomolecular Information Systems or BIS), the nervous systems (also named as Neural Information Systems or NIS), the immune systems (Immune Information Systems or IIS), and the societies (Social Information Systems or SIS). Their imitation has allowed the formulation of cross-disciplinary theory, such as Artificial Intelligence, Fuzzy logic, agent-based modeling and the game-theory, swarm intelligence, cellular automata, and others.
   B) In the second program, researchers exploit the physicochemical law to make computations. Every physicochemical law describes a causal event, and any causal event can be conceived as a computation. The causes are the inputs, the effects are the outputs, and the law governing the transformation is the algorithm of the computation. For instance, we can exploit the laws of quantum physics for making quantum computing.

2.4 Students´ understanding

Teaching global systems thinking in the early school years will give the next generation a clarity of vision and flexibility of mind that will help greatly as the availability of resources tightens [23]. If chemical topics are made relevant to students' lives and society, students' motivation increases [24]. It is also effective if students are involved in changing and designing new curricula with the holistic introduction of the sustainability as an integral part of the didactic practices [25].

In the field of Urban planning and Landscape design, Andersson [18] provides what are called the "Design principles for hierarchically nested green solutions." Such principles allow students to familiarize with the concept of scale. Besides their importance for professionals, these principles offer the opportunity to address urban green infrastructure in class with a refined systemic approach.

The review by Gu et al. [26] helps students to understand geo-design. Geo-design is presented as:

(1) a geography-centred multidisciplinary science,
(2) an iterative design process,
(3) a community participatory planning tool
(4) a process for exploring landscape-based sustainability-oriented ideas.

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Students understand how the geo-design processes are non-linear, iterative, and overlapping. They learn how to visualize multidisciplinary scientific information within a geographical context to make complexity science understandable for people from different fields and communicate with each other efficiently. The paper can help students in the identification of similar functional elements and spatial scale properties in the landscape.

2.5 Development of a toolbox

We report a list of possible toolboxes:

- *Natural Computing*. Complex Systems' investigation demands the collection, storage, and elaboration of massive data sets, i.e., the so-called Big Data. Therefore, it is compelling to contrive smart methods and tools to face the enormous volume and the fast stream of data, their variety (they might have many types of formats), variability, and their relationships. Computer simulations are alternative ways of performing experiments on Complex Systems. It is urgent to accelerate the rate of our computing machines and extend their memory space. New algorithms are inevitably needed to face the Complexity Challenges. There are two promising strategies to succeed. One is by improving the electronic computers, and the other is the interdisciplinary research line of Natural Computing [3, 5]. Natural Computing is an interdisciplinary research line drawing inspiration from nature to propose: (I) new algorithms; (II) new materials and architectures to compute; (III) new methodologies and models to interpret Natural Complexity. The rationale is that every natural transformation can be conceived as a computation, because any distinguishable physicochemical state of matter and energy can be used to encode information. Natural Computing is suitable to tackle the Complexity Challenges [3, 5]. Within Natural Computing, there is Fuzzy logic that is suitable to rationalize the way humans "compute" by using words. The conventional quantitative techniques of system analysis are intrinsically unsuited for dealing with humanistic systems. The basis of this statement is the principle of incompatibility. The essence of this principle is that as the complexity of a system increases, our ability to make accurate and yet significant statements about its behavior diminishes until a threshold is reached beyond which accuracy and significance (or relevance) become almost mutually exclusive characteristics. To deal with humanistic systems realistically, we need approaches which do not make a fetish of accuracy, rigor, and mathematical formalism, and which employ instead a methodological framework which is tolerant of imprecision and partial truths. This methodological framework is fuzzy logic [27]. Other relevant toolboxes are reported below.
- *Systems thinking tools and strategies* can help students zoom out from the large body of detailed and fragmented disciplinary content and obtain a more holistic view of chemistry. The use of systems thinking by educators and learners develops the ability to understand and interpret complex systems [54]. It can help to: (1) Visualize the interconnections and relationships among the parts of a system; (2) Examine how behaviors change over time; (3) Examine how system-level phenomena emerge from interactions between the system's parts. Systems thinking is useful to educate students about the molecular basis of sustainability, to assist chemistry to contribute meaningfully and visibly toward the attainment of global sustainability agendas. Systems thinking tools such as systems thinking concept map extension (SOCME) visualizations assist in highlighting inputs, outputs, and societal consequences of this large-scale industrial process, including both intended and unintended alterations to the planetary cycle of nitrogenous compounds [16]. Systems-Oriented Concept Map Extension (SOCME) tool can aid in exploring, understanding and depicting both within-system and cross-system interactions and in managing complexity. It is more than the Concept Maps because concepts, ideas, and effects are divided in subgroups [28]. Systems thinking is also a useful lens for understanding the underlying theoretical mechanism of geo-design [26]. The multidisciplinary approach in geo-design processes reflects the ecological, social, and economic issues that make up a landscape. Furthermore, the core concepts of systems thinking are hierarchy, adaptability and resilience, the adaptive cycle, connectedness and incorporation, innovative potential, emergence and self-organization, and feedback.
- *Network analysis* is relevant to investigate any Complex System. It is valuable to apply it in the case of Urban Green Systems (UGSs) [29]. UGS's network is formed by protected areas as parks, forests, or other forms of formal green spaces, and all those parts of urban land area covered by vegetation and water. Green spaces are often highly fragmented, and each green patch is segregated from the others [30]. Both planned and natural areas, large and small areas, all of such spaces and their functional connections and interrelations provide a broad range of services to urban residents [31]. Indeed, the pocket and small green spaces offer complementary functions to the 'backbone' of larger green spaces [32]. Private gardens interact with public

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green spaces giving aesthetic enjoyment [33]. Different types of open spaces interact to shape the overall recreational value of the UGS [13]. Network analysis also investigates the spatial interaction of the UGS with its environment [34, 10].

- *Service Learning and Participatory Processes*. Service Learning is useful to conceptualize and implement systems thinking into the classroom. Service-learning is a teaching strategy that intentionally engages students into communities through service activities to address or describe a "real-world" need or issue to serve that community directly. Through Service-learning, students understand course content, a broader appreciation of the discipline, and an enhanced civic responsibility sense [35]. In decisions and actions concerning the urban context, it is crucial to involve the local community directly. Menconi et al. [13] develop a participatory, inclusive process for designing urban green areas with the whole local community, using face-to-face and online tools, steps of reflection, steps of discussions, and game steps to obtain a shared and people-oriented design. Cillier et al. [10] use storytelling to valorize the sense of place and facilitate people-placemaking of public open spaces. Gregorio and coworkers [36] use the systems thinking approach in a participatory process aimed at forest restoration in a developing county in the tropics. The case study proved that the complex interaction of many factors (including biophysical, technical, socio-economic, and governance) acts for the success of community-based forest restoration and requires a system thinking approach.
- *Internet of Things.* Monitoring of urban green dynamic and complex systems requires technological solutions which provide easy data collection, processing, and utilization at affordable costs. To meet these challenges Matasov et al. [37] have conducted a pilot study by using a network of wireless, low cost, and multiparameter monitoring devices, which operate using Internet of Things (IoT) technology. Internet of Things technologies are easily understandable for students. Students can observe plants as living elements that change their performance based on their species, moment of life, state of health, and ways of governance. IoT technologies provide real-time monitoring of regulatory ecosystem services in the form of meaningful indicators for both human health and environmental policies. IoT is a new opportunity to establish a smart urban green infrastructure operational system for management.

  Social media. Social media, such as TikTok, could be valuable tools to spread notions and methodologies related to Systems Thinking. They are more appealing to young generations and more direct information channels, addressing also the needs of the divulgation and communication with nonexperts [38].

2.6 Discussions with teachers

Teaching must be more question-driven than knowledge-driven. It is necessary to revamp our chemistry curricula, pedagogical practices, and assessment tools to shift the focus of attention from the development of pieces of knowledge to the construction of mindsets that help understand and investigate complex systems [39].

Complexity Science is urgent if we want to tackle the XXI century challenges. The XXI century challenges are called Complexity Challenges because they regard Natural, Bioethical, Computational, and Descriptive Complexities [3, 17]. Thermodynamics, Non-linear dynamics, and Networks Science are interdisciplinary theories that are valuable to describe Complex Systems [5] Interdisciplinary topics help to promote students' interest and motivation because of their applications in real situations, concerning in particular ethics and environmental issues [40].

Education on Sustainable Development needs to be considered as a social engagement and requires the involvement of students, educators, professionals, and the public of non-experts [41]. *For Philosophy and Sociology Teachers.*

Social complexity eludes the traditional systems of control and surveillance [42-45] and requires a reformulation of thinking and a redefinition of the fields of knowledge [46, 47], which should play a part in reducing exactly that complexity, or at least in defining the conditions of predictability. Edgar Morin speaks about "thought reform": "Thought reform would require a reform of teaching (in primary school, secondary school, university), that in turn would require a reform of thought. Clearly, the democratization of the right to think would require a paradigm revolution which would allow complex thought to reorganize knowledge and connect the fields of knowledge that today are confined within the disciplines. […] Thought reform is a key anthropological and historical problem. This implicates a mental revolution even more important than the Copernican revolution. Never before in the history of humanity have the responsibilities of thinking been so huge. The heart of the tragedy also lies in thought." [48, 49].

Another "fact of life" is that we are not ready to face the challenges and the dilemmas [50-53] of (hyper)complexity in terms of methodology and research. We need theoretical-interpretative models that should guide or orientate the empirical observation of phenomena and processes. We need to teach and educate to complexity. This requirement entails promote multi- and inter-disciplinarity. Unfortunately, there are concrete hurdles that hamper interdisciplinarity: they are the separations and the disciplinary barricades – take, for example, the longstanding, and in some way, unbelievable distinction between the humanities and scientific studies, between humanistic and scientific training that not only stifles the observation and comprehension of reality, of social production and of knowledge sharing, but which also reveals itself to be incapable of reflecting our current social, political and cultural processes.

The real issue is that we have never been (and are still not being) educated and taught to recognize the hypercomplexity: in other words, we continue "to see systems as objects instead of vice-versa". An inadequacy which has become even more apparent in this society of interdependency and of global interconnections: a "new ecosystem" in which everything is (or at least, appears to be) linked and connected, within non-linear processes and dynamics, with many variables and con-causes that must be considered. A hypercomplexity, that is a cognitive, social, subjective, and ethical hypercomplexity that touches every aspect of life and praxes, and which consequently requires to rethink our categories, our education, our "forms" of citizenship. To put it in other terms, we must measure ourselves with a hypercomplexity that will force us to deal with several urgencies:

A) The urgency to overcome the old linear and cumulative models that are still profoundly affecting the structure and the very organization of fields of knowledge.
B) The urgency, once and for all, to go beyond the logics of separation and reclusion of fields of knowledge that, in reality, limit the educational and formative processes within individualistic dynamics that consent solely the transmission of knowledge, and not its communication and sharing.
C) The urgency to overcome the traditional idea or view of learning as a process of accumulation of knowledge, in view of increasingly complex and articulate learning processes that are, above all, more and more oriented towards cooperation and collaboration.
D) The urgency, not only to reorganize didactic-formative itineraries, encouraging interdisciplinarity and multidisciplinarity (fundamental), but to actually reformulate the entire system of thought, increasing the knowledge of knowledge, with greater awareness.

What a complex question complexity is! And in coping with it, we cannot avoid once again considering one essential element: currently, cultural evolution is capable – as never before—of conditioning biological evolution, determining an anthropological transformation which further highlights the urgency of that paradigm shift we need so sorely. Since hypercomplexity is not an option, it is, as we said before, a "fact of life"; the real problem is that we have not been taught or trained to recognize it, or at any rate, not by using our own heads. For some time now, "technology has begun to take part in the synthesis of new values and new evaluation criteria, bringing out, even more clearly, the centrality and the strategic function of cultural evolution, which is unrolling alongside biological evolution, deeply conditioning it and determining dynamics and retroactive processes (such as, for instance, the technological progress linked to artificial intelligence, robotics, IT, nanotechnologies, genomics, etc.)" [9].

- *For Chemistry Teachers*.

When chemistry embraces systems thinking, it is surely a central science: it can bridge all the other scientific disciplines that deal directly or indirectly with the matter [54]. Globalization created a more direct relationship among law, ethics, social sciences, and chemistry. Global competence can be defined as "the capacity and disposition to understand and act on issues of global significance [55]. Chemistry educators can play a fundamental role by helping students to understand how fields such as economics, politics, and law interact with natural sciences by a systemic point of view, in order to establish rational energy policies, to promote technological innovation, to reduce dependence on fossil fuels, and so on. Furthermore, disciplinary and interdisciplinary concept teaching by a systemic approach enhances students' higher order cognitive skills [55].

The role as a junction between the animate and the inanimate world makes chemistry a "central science", whose range of influence affects the natural environment as well as health, socio-economic, and ethical issues. In this context, chemistry education may play a key role in helping students to develop thinking skills such as analysis, categorization, and evaluation of phenomena [40].

The pedagogical approach developed by SENCER (Science Education for New Civic Engagements and Responsibilities) is one way that faculty could reorient chemistry courses toward a systems perspective and provide increased emphasis on the ethical nature of chemistry's impact on society. An undergraduate chemistry curriculum that educates "head, hands, and heart" offers great potential to prepare students to become chemists that are fully committed to the vision of "improving people's lives through the transforming power of chemistry". It is important to form the new generations of chemists and professionals by developing three distinct dimensions: (1) the cognitive dimension (i.e., the "head"); (2) the skills' dimension (i.e., the "hand"); (3) the ethical dimension (i.e., the "heart").

This new approach is reasonable if it is accepted that the practice of science and the use of its knowledge should always aim at the welfare of humankind, including the reduction of poverty, be respectful of the dignity and rights of human beings, and of the global environment, and take fully into account our responsibility towards present and future generations [56].
There are three pathologies of learning: (1) amnesia, i.e., forgetting by students what they have learned; (2) fantasia, i.e., illusionary understandings or persistent misconceptions that students retain over an extended period of time; (3) inertia, i.e., ideas learned in a way where students are unable to use these ideas in thinking or to apply them to new situations. To fight these learning's pathologies, it is necessary to reorient chemistry education by presenting concepts and theories with a problem solving's approach [56].
Systems thinking, including green and sustainable chemistry, shows promise as an approach to help chemistry students zoom out from detailed and fragmented disciplinary content to obtain a more holistic view of chemistry and its integral connection to earth and societal systems [54].
It is necessary to stimulate well-trained chemical specialists on the concepts of green chemistry within the context of chemical sustainability. Sustainable Chemistry Education should be proposed in other disciplines such as social sciences, economics, law, humanities, et cetera [57].
It is worthwhile noticing that the system thinking approach has not to replace the reductionistic one but they have to be used together to obtain a synergistic effect both in chemistry and chemical education [58].
Systems Chemistry consists in the design and implementation of complex molecular systems characterized by emergent properties, which "go beyond the sum of the characteristics of the individual constituents of the system." Systems Chemistry can be a valuable subject to teach Complex Systems. The teachers can propose subjects such as (1) Transient dissipative non-equilibrium self-assembly; (2) Chemically fueled molecular motion; (3) Compartmentalized chemical networks; (4) Designed oscillators [59].

- *For Landscape Planning and Design Teachers.*

Yocom and Johnson [60] find students have difficulty with: 1) comprehending the complexity of core ecological concepts and their spatial relevance; 2) incorporating the temporal aspects of biophysical processes; 3) focusing on the sometimes-intangible qualities of relationship-building; and, 4) using a non-linear approach to the narrative representation of design proposals.
Emerging pedagogical frameworks in education are shifting to a more systems-based approach focusing on the recognition of relationships and functional processes of engagement over the need to identify specific and static solutions or responses. While Landscape Architecture programs may already incorporate systems- based pedagogy in their design curriculum, the scope of literature available for how this is done is relatively limited. Yocom and Johnson [60], highlighting the difficulties experienced by the students in comprehending the complexity of the phenomena addressed by the course, offer some useful suggestions to teachers to approach the issues of landscape planning and design:

- Regarding the landscape design's objective, the authors suggest that teachers need to focus less on the physical components and more fully on the relationships and patterns that form cohesion and support function within the system.
- Systems-thinking in design education should be focused on 'how' and 'why' something works. Instead of characterizing the design process as a bounded, linear progression, it should be taught and understood as iterative and responsive.
- The focus should be on the design's functional potential rather than the aesthetic in a design studio.

Cilliers et al. [10] report some examples of the requalification of public green spaces using storytelling and placemaking approaches. Storytelling can be a formidable tool for transferring the basic concepts of complex systems theory.
Whitburn et al. [61] discuss the challenges of teaching and learning interdisciplinary and collaboratively in an architectural education. They present an experimental master's studio at Victoria University of Wellington, where they address the challenges associated with the successful integration of different disciplinary design perspectives, pedagogical and conceptualization approaches, and they reflect on cultural and disciplinary domains that enabled authentic learning in design education.

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2.7 Discussions with employers

Globalization created a more direct relationship among law, ethics, social sciences, and chemistry. Global competence can be defined as "the capacity and disposition to understand and act on issues of global significance [55]. Complexity Science is urgent if we want to tackle the XXI century challenges. The XXI century challenges are called Complexity Challenges because they regard Natural, Bioethical, Computational, and Descriptive Complexities [3].

We see a re-emergence of polymathy and generalism as both valued educational ambitions and central to the future of work. We are entering an age in which greater connectivity (of information, products and people) and increased complexity bring significant and frequent changes to what is required in work outside universities. However, academic disciplines, established in the West roughly during the late 18th and 19th centuries and now deeply ensconced in university cultures and organizational structures, can find it hard to mirror these changes and to respond. Universities should form not only specialists but also generalists and polymath [62].

It is only through working together that science, society, and policy can serve as a dependable vaccine to prevent and prepare for the adverse impacts of emerging threats and as a potent antidote that can treat and minimize ensuing harm to health, economies, and the environment. The essential glue that bonds this combination together is trust in science, honesty and ethics. This compact between science and society must also recognize that uncertainty is intrinsic to the human condition and that it is necessary to expect the unexpected. Science, for all its own uncertainties and continuous need to verify and sometimes revise or update its conclusions, remains the best available guide on the pathway to navigate uncertainty [63].

- *Pharmaceutical and healthcare firms.*

The systemic approach is required in Medicinal Chemistry, a discipline that is involved in the study of the molecular interactions of drugs with the complex chemical network of a living system. Looking at the past (as well as at the present) there are no examples of molecules selected by means of a single biochemical essay that achieved an effective therapeutic response, demonstrating the inefficiency of a reductionistic approach in the discovery of new therapeutic agents for complex disease indicating the needs of new complex biological assays for a more efficient and reliable selection of new candidate therapeutics, passing from the reductionistic interpretation of a single in vitro test to a multivariate assay with multiple endpoints. The novel approach needs to consider that drugs should interacts not with the acute short-term physiological systems, but they have to promote a long-term regulation of the entire network of systems [64]. A very interesting example can be found in the oriental medicine and therapies that have a traditional holistic approach in the interaction between molecules and living systems. In this case a reductionistic study is not able, alone, to drive a modern elucidation of the mechanism that are on the basis of these therapies and only an efficient combination of top-down and bottom-up approaches should disclose the basis of the physiological interaction responsible of the effects produced by this kind of medicine [65].

A cell model is not able to summarize all the facets of the in vivo chemical biology, and this limit could be overcome integrating data from multiple models representing different levels of complexity (e.g., omics sciences), taking in considerations also the dynamic component of pathological processes and diseases. Nevertheless, also these attempts present several examples of fails often carriable to a not efficient level of communication between the "wet-lab" and the bioinformatics that should be resolved with the creation of a different kind of scientific training as well as a new approach in the collaborations, all aspects that are usually not demanded by the reductionistic approach and that should involve the joint efforts of academy, industry and educational institution [66].

In the field of drug discovery several networks need to be considered, also from a computational point of view: i) Networks for the Analysis of Molecules Data Sets; ii) Protein Structure Networks; iii) Human Disease Network and Drug Discovery. The needs to simplify these networks lead to the problem of missing information that is a common issue in the studies of biological systems and that should be addressed with the optimization of prediction methods also in the study of the network dynamics, a strategy largely unexplored since now but with a strong potential in the development of new approaches to the drug discovery processes in which the classical computational drug design is integrated in a more complex network context [67].

The pharmaceutical production, as well as, any other industrial production can be strongly demanding in terms of energy and feedstock and are responsible of a large number of wastes that require treatments before the disposal. A pharmaceutical product is a mixture of compounds each one characterized by its life cycle assessment (LCA) and the overall LCA is not simply the sum of these ones. This issue needs to be approached considering the production of a pharmaceutical preparation as a complex system with its interaction within environment ecosystem(s). This latter part involves also the use of the drugs and their metabolization with the production of other chemicals that are returned to the environment [68].

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As a further shell of interaction drug discovery processes need to be considered in the general context of the public health challenges. In this extended network several other systems need to be included and analysed: politics, economy, ethic, democracy. As an example, the neglected tropical diseases, represents a complex global health problem responsible for a large disease burden among poor populations around the world. Some key actions to change the current system can be identified approaching this issue with a system thinking approach considering all the key forces and feedback loops from which the authors identified five leverage points and a series of unanswered questions [69].

Complex diseases are characterized by conditions caused by a large number of genetic and environmental factors and by all the interactions among them. Many common diseases, (e.g., asthma, diabetes, epilepsy, hypertension, major depression, Alzheimer's, and food allergy) are complex diseases and need to be investigated as a complex biological system composed by different subsets of biological systems (e.g., genome, metabolome, microbiome, transcriptome). Even if the omics sciences represent a good answer to the study of systemic biology need a further development of these techniques passing to a multi-omics approach, increasing the analytical ability to study interconnected contiguous complex systems [70].

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