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GENERAL INFORMATION

The dimension of the paradigm of complexity in health systems☆

Guillermo Fajardo-Ortiz*, Miguel Ángel Fernández-Ortega, Armando Ortiz-Montalvo and Roberto Antonio Olivares-Santos

Subdivisión de Educación Continua, División de Estudios de Posgrado, Facultad de Medicina, Área de Sociomedicina, Universidad Nacional Autónoma de México

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Abstract
This article presents elements to better understand health systems from the complexity approach, a position that moves away from the linearity, rigidity, and directional. It is characterised by the study of the emergence of unexpected behaviours, oriented to explain and understand more completely what happens in health systems. The current systems are becoming overwhelmed.
The complexity paradigm represents a conceptualisation different to the prevalent epistemology, non-isolated, non-reductionist, or fixed. It does not solve the problems, but presents other bases to fully understand the physical, biological and social systems. It is a perspective that has its basis in the systems theory, informatics and cybernetics beyond traditional knowledge, the positive logics, Newtonian physics and symmetric mathematics, in which everything is centred and balanced. It is the link between the "soft" and "hard sciences, and takes into account the determining factors of social health and organisation culture.
Under the complexity paradigm the health systems are identified with the following concepts: entropy, negentropy, the second law of thermodynamics, attractors, chaos theory, fractals, self-management and self-organization, emerging behaviours, percolation, uncertainty, networks, and robustness. These expressions open new possibilities to improve the management and better understanding of the health systems, giving rise to consider health systems as complex adaptive systems.

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*Corresponding author: Juárez 14, Casa 11. Col.: Tlacopac, San Ángel. Deleg. Álvaro Obregón. C.P. 01040 México D.F., México. Teléfono: 5628 1008, 5623 7253.
E-mail address: gfortiz@unam.mx (G. Fajardo Ortiz).

PALABRAS CLAVE
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La dimensión del paradigma de la complejidad en los sistemas de salud

Resumen
Se presenta información para entender los sistemas de salud desde el enfoque de la complejidad, posición que se aparta de la linealidad, lo rígido y lo direccional, caracterizándose por el estudio del surgimiento de conductas inesperadas, orienta a explicar y entender en forma más completa lo que ocurre en los sistemas de salud; los esquemas actuales están llegando a su agotamiento. El paradigma de la complejidad representa una epistemología diferente de la prevalente, no aísla, no es reduccionista, ni «acartonada» en cuanto a saberes, ni pretende resolver problemas; presenta otras bases para conocer en forma más completa los sistemas físicos, biológicos y sociales. Tiene como fundamentos la teoría de sistemas, la informática y la cibernética, va más allá de los conocimientos tradicionales referentes a la lógica positivista, la física newtoniana y las matemáticas simétricas, en que hay equilibrios. Trata de vincular las ciencias «duras» y «blandas», tiene presente los determinantes sociales de la salud y la cultura organizacional. Mediante este paradigma, en los sistemas de salud hay «cuantización» y «matematización», manifestándose, entre otros, a través de la entropía, la neguentropía, la segunda ley de la termodinámica, los atractores, la teoría del caos, los fractales, la autogestión y autoorganización, las conductas emergentes, la percolación, la incertidumbre, las redes y la robustez; dichas expresiones abren nuevas posibilidades para conocer y mejorar los sistemas de salud, en cuanto a su gerencia, en que hay continuos zigzags, surgimientos, desapariciones, crecimientos, afirmaciones, negaciones y contradicciones, considerando a los sistemas de salud como sistemas complejos adaptativos.

«What comes into the world to disturb nothing deserves neither attention or patience».
René Char (1907-1988), French poet

Tradition and innovation

It has been four decades since the complexity paradigm emerged in scientific endeavour, a stance that expresses a separation from what is mechanical and unidirectional, from traditional logic and mathematics; it is a strengthening viewpoint that unifies disciplines. It separates from the ideas of the philosopher, mathematician and physicist René Descartes (1596-1650), from the ideas of the British physicist and mathematician Isaac Newton (1642-1727), from the ideas of the French sociologist Augusto Comte (1798-1857), from the ideas of philosopher and mathematician Bertrand Russel (1872-1970) and from the ideas of the Austrian philosopher and sociologist Karl Popper (1902-1944), amongst others, but it acknowledges that their contributions have been very valuable, accepted and disseminated within many scientific fields.

Based on the complexity paradigm, it is considered that systems —physical, biological and social—, are composed of agents that are separate and different (intellectual, time, physical resources, financial resources, people, parasites, vegetables, minerals, etc.), in which unstable and non-recurring behaviour arises, in which the characteristic feature is that everything changes, new things constitute what is innovative, the same as with unexpected things, random things and qualitative things. Processes are intra and transdisciplinary; there are implausible combinations, which diverge from deterministic chains, which are reductionist points of view[1].

Science is variable, transforming; it is constantly seeking and trying to attain a greater incorporation of scientific knowledge. How can we explain the current phenomena without trying to take into account all their components and causes, without a comprehensive view? The explanation of a series of phenomena that compile in a linear manner constitutes an initial approach; trying to understand them from a complexity perspective involves integrating, unifying, disassembling, reassembling, and analysing the phenomenon and the setting as a whole. Let us remember that the etymology of the word complexity comes from the Latin *"complectere"* which means to connect, encompass, obtain something that is beyond comprehension. It suffices to say that complexity is usually associated with the word problem and perhaps this is because, when facing certain problems and looking for a solution, we have numerous options that can be varied and heterogeneous, which makes us perceive various elements interrelated amongst each other and situated almost in the same context.

A globalised world and access to modern communication systems, which in turn favours the incorporation of new knowledge and techniques, together with an epidemiological transition, an increase in costs, and the models of interaction in healthcare, from social models or private and/or public medicine, determine that the analysis and understanding of healthcare systems should be complemented with the complexity paradigm, to improve its efficiency and quality.

An indefinable notion

There is no single notion of the complexity paradigm, but it depends on the field of study and the researcher. We must take into consideration that it is being shaped, that it does not have a precise approach, perhaps it never will. It has its own language, which will probably contribute to the scientific language of the future, it is a new lifeblood, rich in knowledge; it breaks traditions.

The foundation of the complexity paradigm is systems theory, computer science and cybernetics, which are based on quantum physics and non-linear mathematics. In a way, it constitutes a challenge to the prevailing common sense, it overthrows traditional logic.

This approach is comprised of new alternatives, averse to the analysis that arbitrarily separates reality and studies it in isolation and fragmented by specialised disciplines, which accepts deterministic logic and the proportionality between cause and effect. The study of complexity is based on mathematics that examine variability, the evolution of complex systems distant from equilibrium (on the edge of chaos), as opposed to looking for structure, laws and stable associations. It is focused on the study of the connections between components in open systems, rather than on the study of the systems themselves. These mathematics include a wide range of developments: power laws, dissipative structures, phase transitions, bifurcations, irreversibility, chaos theory, strange attractors, fractals and network theory, among others. Complex systems are essentially characterised by the emergence of phenomena that make them unpredictable, but also by their non-linearity, high sensitivity to initial conditions and self-organization, which justifies the rejection of any reductionism and the need of interdisciplinary work on borderline issues, which is highly counter-intuitive. Emergence refers to the manifestation of phenomena or attributes within a system that are not generated by external agents, nor can they be explained as a consequence of their isolated elements, but only according to the non-linear interrelations that arise between them. The emergence of new behaviour structures or patterns under these conditions is a result of the system's self-organization processes. They involve changes that cannot be explained in terms of causality or gradualness, which arise spontaneously; consequently, they create unpredictable transitions between order and disorder.

When speaking about complexity in healthcare systems and organisations, there are several approaches regarding what is intended to be emphasised. For instance, component interactions of the system, understanding and inclusion of organisations, the existence of dissipative structures, diversity and changes in the notion of times, to name a few.

Acknowledging this model in healthcare systems means accepting dynamics characterised by polarization, cohesion, integration and disintegration processes; that is to say, there are interrelations that are not organised, in which new characteristics emerge, which were not planned or known from the agents of the system. This gives rise to information and situations that are different from what is expected; they are multi-faceted processes that do not entail direct cause and effect relationships, in which their dynamic is incomplete[2].

By approaching the organisation as a whole, to analyse its constant moves, with changes in human, physical, material and technological resources, its disposition, work processes, and its interrelation with the environment and other organisations, the complexity paradigm allows us to study not only the variables in context, but also the interrelation between the components of each process directly and globally.

Social determinants of health and organisational culture

The state of health/disease of the population depends on various factors, among which are: the country's financial condition, the level of income of individuals and families, genetics, diet, the level of education, lifestyle, the socio-demographic and environmental characteristics of each region, government resources and programs dedicated to healthcare. The health/disease of the population depends on the interaction of these and many other elements in such a way that, nowadays, phenomena that are little expected and difficult to understand with a reductionist approach emerge, such as ageing and chronic degenerative diseases, violence, AIDS, obesity, diabetes mellitus and influenza outbreaks, among others, for which the tools that the complexity approach offers can provide greater clarity and insight[3].

On the other hand, in healthcare systems that are organised vertically and in a centralised manner with a healing approach, we can confirm that there are currently not enough staff members-managers with academic training and professional experience that would prepare them to efficiently perform their duties, which at an operational level have significant consequences in the services that healthcare organisations offer and the health impact in the population they assist: isolated or focalised activities within healthcare organisations, poor channels of communication, lack of sense of belonging to the organisation, poor administration of operating resources, non-timely maintenance of facilities that causes their deterioration, lack of resources to maintain, restore and acquire new technologies, fluctuating operation and quality policies, which leads to a partial establishment of processes for the operation and the assistance of internal and external clients belonging to these organisations. Based on the social determinants of health and the organisational culture, we may consider that in healthcare systems under the complexity paradigm, people emerge in their individuality and as a group, becoming players, spectators, speakers and audience members (patients, community, visitors, family members, doctors, nurses, staff members, etc.) in different times and spaces. In this situation, the healthcare system is a complex adaptive system, non-static, since it adapts, shapes and changes itself according to experiences, stimulation, communication, information and the environment.

Paradigm operational keys

The complexity paradigm operational keys or attributes that can be applied to healthcare systems are processes similar to the ones in other sciences, especially in 21st century physics and mathematics. Attributes overlap, in different scales; they are not easy to demarcate or conceptualise. They are, among others: entropy, negentropy, the second law of thermodynamics, attractors, chaos theory, fractals, self-management and self-organisation, emerging behaviour, percolation, uncertainty, networks and robustness. These fundamental expressions involve information and thresholds for change, which enable knowledge and improvement of healthcare systems, since they unify and correlate hard sciences with soft sciences, two types of related sciences that intertwine in grey areas.

We must be clear about some notions regarding the systems' environment

Entropy. It refers to the end of a specific system, explained in the loss of an organisation, especially in isolated systems (without energy interchange with the environment), which end in total degeneration. These types of systems are destined to have a chaotic and destructive end; despite their attempt to seek stabilisation, they will collapse in chaos and disorder. Even though it affects closed systems, it also affects open systems when trying to combat entropy, generating something called negentropy. It is the breakdown of the system's structure, to the point that elements cannot be distinguished from one another, nor can their functions be defined, since the energy accumulated inside the system begins to disseminate evenly inside of it, altering the well-defined properties of its elements, turning them more homogeneous, which causes disorder and chaos because there are no elements with well-defined functions inside the system.

Negentropy. It is the opposite of entropy; it is oriented towards order and stability within open systems. It specifically refers to the energy imported and saved by the system (energy extracted from its external environment), for its survival, stability and improvement of its internal organization, and, therefore, it is a mechanism of self-regulation, capable of sustaining itself and maintaining balance.

It is the organization and administration of energy, in such a way that it does not alter the properties of the rest of the elements of the system, so it can continuously move and enter and exit the system through regulating mechanisms, thus avoiding accumulation and homogenization of the remaining elements of the system.

Second law of thermodynamics. Systems can be classified in open or closed: the first interchange material, information, ideas and emotions with their surrounding environment; the second remain isolated; logical predictions take place in them. This law indicates that within an isolated system, entropy tends to increase over time, and there is a tendency to a progressive degradation or to the destruction of the structures of said system, which achieves a state of equilibrium when it reaches its highest value. This refers to living systems, which can feed on negative entropy from their surroundings (healthcare assistance, antibiotics), which enables them to resist said law and prolong life.

Attractors. They are agents or elements that attract; they motivate other systems to follow a certain behaviour or path. In organisations, they can be reference points that favour organisational functioning in different dimensions, but at the same time, they establish limits for the performance of variables. Some examples of these attractors are the organisational or the system's objectives, the products offered, the executive staff, among others.

Chaos theory. It establishes that small changes to parts of a system can give rise to intricate states or unexpected results. It does not mean disorder; it is a new order, perhaps more perfect, although that cannot be completely unravelled for the time being[4]; it could be said that reality is deceiving.

Fractals. Chaotic behaviour can give rise to fractals, representations similar to preceding ones. In a way, they are a reproduction of those representations. Benoit Mandelbrot (1924-2010), a Polish mathematician, coined the word fractal when studying and analysing the heart rate. He visualised mathematical phenomena, he pointed out the inconsistency, indicating that its variability is essential for life, adding that the analysis of an electrocardiogram looks the same in a period of 10 minutes and in one of 10 ms. Fractals are different from Euclidean geometry (300 B.C.), which features regular representations[5].

Self-management and self-organisation. It means the system's agents unify and reconform; they reorganize themselves, resulting in other different managements and institutions, which can originate in chaos and fractals. In other words, it is the ability systems have to self-adjust and to change their organisation and ways to run according to internal and external dynamics.

Emergent behaviour. It comprises new system paths or paths that were not taken into account, which arise unexpectedly[6]. It is the result of the connection of systems, and can be identified with chaos, fractals and networks.

Percolation. It refers to the dissemination of information based on non-linear mathematics, which depends on movements of self-management and self-organization, emergent behaviour and networks.

Uncertainty. It expresses that there can never be certainty about the position, change and speed of system components and the systems themselves; when it is estimated that there could be accuracy in any systemic process, the opposite may happen. This is considerably due to environmental dynamics[7]. It overthrows prevailing logic; in a way, it is "counterintuitive."

Networks. It involves a concrete and inevitable relationship between the system components, regardless of the results intended, since many of its nodes are connected; they interact with each other[8] and their separation is impossible because they share information.

Robustness. It refers to vigorous, strong or firm things. It refers to physical or symbolic characteristics. It involves resilience, which is the systems' ability to endure changes; they continue to function as they did before, to a large extent. It is a way of automatism. It can be understood as an attribute of the system in question that has the ability to prevail by virtue of its strength and consolidation. An organisation that has been working properly for several decades shows its robustness by having stood the test of time. The above is possible due to the quality of services and the ability of the managerial staff. An example of this could be an emergency department that, in spite of a sudden increase in services, has the ability to maintain proper quality standards.

On the other hand, no one could stress the robustness of an organization that begins to have defects in its services after two or three years of being founded, since this is an unstable and vulnerable organization.

Constructs and systems frameworks

Traditionally and schematically, systems have been considered as composed by "links" that form a chain: supplies, processes, results and feedback. Actually, said "links" overlap and are difficult to demarcate. In them are various agents that affect each other and are affected by the environment[9] due to the system's own information and the information coming from other systems.

Supplies or inputs are considered the beginning of a system, which implies: patients, history, traditions, experiences, strategies, health policies, controls, innovations, expenses, intellectual powers, human resources, organisational hierarchy, physical resources, financial resources, information media, energy, etc. Inputs constitute the original premises, with different identities that converge in what is considered the beginning of the system.

Processes or transformations unify, convert and modify inputs. It is unknown when they begin; inputs are gathered, and are sometimes deemed incompatible, giving rise to results. Some examples of these processes are: decisions, negotiations, services, technological developments in general and in particular about information and communication, training, research, innovations, epidemics, diseases and accidents, to name a few.

Results or outputs are heterogeneous products of processes: discharges, operational costs, institutional morbidity and mortality, complaints and medical-legal lawsuits.

Based on the abovementioned information, we must reaffirm that healthcare systems do not have a probabilistic behaviour; they do not follow deterministic behaviours; they are not predictable in any aspect, as is the case with the complexity paradigm. Therefore, they cannot still be considered links or "sequential lines", in which inputs, processes, results and feedback are connected unidirectionally; that is a misconception, since systems are identified with attributes from the complexity paradigm.

Identification of healthcare systems with the complexity paradigm

Healthcare systems are a huge clutter; from a realistic stance, we can state that healthcare systems must look for their authenticity outside the sense that history and the past have instilled in them. Next, we will evaluate the characteristics of healthcare systems more specifically and according to the complexity paradigm. When they are identified with "quantum" and non-linear mathematical attributes, there are parallelisms[10].

Non-linearity. Healthcare systems do not behave sequentially; they do not go through clearly predetermined stages; their paths are not always predictable; their results are usually not uniform and they are unexpected in relation to the mechanisms that generate them. This feature can fit within entropy, uncertainty and networks. For instance, actions destined to improve the quality in the external consultation services of a hospital can be successful at the beginning, but when demand increases due to good results, human resources and materials could be insufficient and schedules could be unsuitable; so it is possible that all resources get tangled and processes altered; quality is modified. Another example in which linearity is broken is when there are vulnerable healthcare systems with regard to leadership and decision-making, which can lead to informal —non-linear— organisations in which unforeseen activities arise and leaderships outside the established organisational chart —lines— emerge.

Constant changes. Healthcare systems are constantly and permanently modified; they form, reform and deform[11]. Inputs, processes, results and feedback are unexpectedly altered as regards number and quality; small modifications generate situations that are difficult to predict, in which chaos theory, entropy, negentropy, percolation, network information and self-management and self-organisation could be identified. For instance, a radiotherapy service (which is an agent or a subsystem of a system of healthcare services), can reduce the period of stay of hospitalised patients, which, in turn, can entail an increase or decrease in service demand in other services and other institutions, causing problems in the level of satisfaction of patients and staff, and probably altering quality and costs.

Interconnections. Relationships between the agents of a same healthcare system or with others mean that any action or modification in them will affect them or the others. For instance, providing haemodialysis services in a hospital that has not provided such services so far can increase demand in external consultation, clinical analysis laboratory and hospitalisation services. Determining the positive and negative effects in healthcare systems regarding interconnections is essential to planning and evaluating long-term results. If interconnections are not taken into account, problems relative to attractors, percolation, networks and self-management and self-organisation may arise.

Feedback. Feedback is information that originates in healthcare systems and returns to them in some way[12]. It is possible to identify it with negentropy, attractors and fractals; some examples are the readmission of patients at a hospital or the historical needs of supplies such as medications or reactives for a month.

Uncertainties. Some actions that are expected to go according to plan usually do not; each simple or complex action creates an impact on the whole system. For instance, planning mammography services in marginal communities can be something that is rejected by the female population for cultural reasons, a situation that can be identified with chaos, self-management and self-organisation, robustness and emerging behaviour.

Relationship with time. Short-term results in healthcare systems can be different from long-term results; these differences can sometimes be underestimated. For instance, at the beginning of a family planning program, services may not have a high demand; subsequently, it is possible that this demand grows. This characteristic is reminiscent of the thermodynamic process and the chaos theory.

Conclusion

The complexity paradigm applied to healthcare systems is giving rise to another form of conceptualisation. It is more realistic, objective and it complements them, since it applies knowledge to better understand their dynamics, resorting to disciplines that have not been considered akin to healthcare systems.

Conflict of interest

The authors declare that there are no conflicts of interest.

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