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The Contribution of Complexity Theory to the Rejuvenation of Philosophy of Education

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In this paper, we endeavor to connect Complexity Theory (CT), a meta-theoretical framework whose ontological assumptions are argued to align more closely with the nature of reality, with the philosophy of education. As a new paradigm, CT is fostered in a variety of fields, including education, where a shift has occurred from a linear, mechanistic, and reductionist approach in learning and development, toward recognizing the complex and dynamic nature of educational processes. Within this context, the paper discusses the main orientations of reductionist and mechanistic approaches, while highlighting the existing limitations. More specifically, this study examines learning and cognitive development through the lens of Complexity Theory, reconsidering them as complex nonlinear dynamical processes, and proposes the amalgamation of the conforming ontological and epistemological conjectures into the philosophy of education. The new perspective can provide a springboard for a rejuvenation of philosophical thought, which could lead to a better understanding and theory, development, and more effective interventions.

Introduction

In this paper, we endeavor to connect Complexity Theory (CT), a meta-theoretical framework, with the philosophy of education. CT is understood as a paradigm whose ontological assumptions are argued to align more closely with the nature of reality, attributing ontological priority to relations rather than to isolated, atomistic entities. Within this framework, educational processes, learning, and cognitive development are reconsidered as complex nonlinear dynamical systems that lead to emergent phenomena through continuous interactions among individual parts, within various social contexts, and under environmental conditions. This shift reflects a movement away from linear, mechanistic, and reductionist approaches toward a more dynamic and relational consideration of educational reality, which captures more adequately the complexity of learning and development processes.

Historically, the concept of *complexity* appeared to describe the difficulty of confronting reality without full rationality. It was initially associated with Simon's ideas emphasizing the limited human capacity in finding truth and in decision making, and with the notion of *bounded rationality* on which the complexity sciences have grown (Simon, 1955; Simon, 1962). Later, advances in cybernetics and nonlinear sciences in the domain of mathematics brought to the discussion core aspects of complex systems, the ontology of which prompted new epistemological issues and affected philosophical thought. Complexity theory emerged through the synthesis and interconnection of various traditions and conceptual tools, including cybernetics, general systems theory, dynamics, nonlinearity, dialectics, and related approaches (Bateson, 1972; Lefebvre, 2009). This synthesis is rooted in the deeper notion of complexity itself as a unifying ontological principle, primarily understood as a mode of existence and evolution.

Currently, Complexity is a well-developed interdisciplinary field that studies systems across nature, living organisms, human and social phenomena, and it has provided a refined understanding of the natural world, science, society, economy, and other domains. It refers to the study of the so-called complex systems, which are comprised of interconnected entities as nodes in a network ontology and characterized by dynamical, nonlinear, and adaptive behaviors in response to changes in both the environment and the system itself. In such systems, relationships play a primary role in determining how components function, often shaping the behavior of the whole system. These systems may be natural, biological, social, or technological, and are defined by multiple and diverse interactions among their components. Accordingly, the relationships between nodes may be as important as the nodes themselves, if not more so (Siew et al., 2019). The collective behavior of the system thus appears as a nonlinear and dynamic function of numerous parallel interactions among its parts (Pathak et al., 2007). Moreover, it refers to open complex dynamical systems with emergent properties and continuous transformation (Byrne, 2005; Byrne & Callaghan, 2013; Jacobson & Wilensky, 2009). This becomes particularly evident in social reality and cognitive phenomena, where human activity plays a decisive role. Essentially, complexity theory concerns the description and explanation of change (Stamovlasis, 2016). However, insofar as it can be considered a meta-theory with a unifying role, its significance lies precisely in the distinct mode of thinking it introduces, which differs fundamentally from that of traditional science (Heylighen et al., 2017; Stamovlasis, 2016).

Investigating complex systems involves identifying the underlying mechanisms that generate behavior and developing causal explanations (Preiser et al., 2018). It is generally accepted that certain properties of these systems become visible only at a holistic level, rather than at the level of individual components. The adaptive nature of complex systems allows them to change and evolve in response to feedback and contextual shifts. In this sense, a complex system exhibits memory and the capacity to learn from past interactions, thereby shaping its present and future trajectories (Preiser et al., 2018). Their internal structure emerges from patterns of dynamic interaction both among components and between components and the broader environment. Unlike linear systems that can be meaningfully isolated from external influence, complex systems incorporate their boundary conditions as part of their structure. As a result, they are fundamentally dependent on context: changes in the environment may alter system structure, function, and the roles of individual components.

For philosophers and educational researchers, studying learning communities as nonlinearly evolving systems offers insight into the conditions under which changes occur. Phenomena such as student failure, dropout, and shifts in emotions, attitudes, or behavior are frequently observed in educational settings. Discontinuities and abrupt changes coexist with smoother, linear patterns across all levels of educational complexity (Stamovlasis & Vaiopoulou, 2017; Steenbeek & van Geert, 2013; van Geert, 2009; van Geert & van Dijk, 2021). This does not allow precise prediction of the timing or outcomes of specific transformations, but it does provide indications regarding conditions under which phase transitions and discontinuous changes are more likely (Steenbeek & van Geert, 2013; van Geert, 2011).

An important characteristic of educational processes, such as conceptual change, problem-solving, learning, and shifts in attitudes or perceptions, is that they are non-ergodic. The notion of ergodicity rests on the assumption that the causes of variation observed between individuals are identical to those governing variation within individuals over time (Molenaar & Campbell, 2009). In other words, it assumes that group-level averages adequately represent individual developmental trajectories. However, this assumption often does not hold, and the traditional approaches become unsuitable for understanding psychological mechanisms operating within individuals (van Geert, 2011; van Geert, 2014). The added value of the complexity perspective becomes clearer when considering the limitations of traditional approaches and specifically on some epistemological aspects, such as determinism and reductionism, that have a direct impact on empirical work (Stamovlasis & Vaiopoulou, 2017) and are discussed in the following section.

The purpose is not to reconstruct the history of epistemology or ontology exhaustively. Rather, it examines how certain dominant assumptions in modern philosophy are challenged and reoriented through complexity theory. The central argument is that CT provides a more coherent framework for educational phenomena insofar as reality, knowledge, cognition, and learning are understood as processes emerging from dynamic interactions within and between systems.

The discussion begins with a brief overview of major epistemological and ontological tendencies in modern thought. It then examines the core characteristics of complexity theory, before exploring its implications for cognition, conceptual change, learning, and educational processes. Finally, it considers the broader philosophical significance of complexity theory for the philosophy of education.

The Prevalence of Reductionism

At the outset, it is widely accepted that any viewpoint and perspective on learning and education is grounded on the nature of knowledge. Thus, approaches to pedagogy are intrinsically linked to philosophy of education and are steered by epistemological presuppositions. This connection is evident in the theories of both Piaget and Vygotsky, whose work, despite the differences, integrates epistemology and the philosophy of mind, contributing significantly to their development. Piaget's theory emphasized the stages of cognitive development and the role of individual construction of knowledge, while Vygotsky focused on the socio-cultural influences and the mediated nature of learning through language (Derry, 2013).

In literature, it has been noted that, for some time, there has been a denial or, to put it more mildly, a lack of prioritization of philosophy of education issues, albeit with some important exceptions (Bakhurst, 2020; White, 2024). Following the debates unfolded, and continue to unfold, in epistemology, one could conclude that the aftermath of the riots has also affected the debate within the philosophy of education.

The controversial issues raised could be attributed to the dominance of Cartesian dualism, the empiricism (Bakhurst, 2020; Bhaskar, 2008). Positivism can also be included in this framework (Smith, 1992), as it emphasizes the individual's reception and cognition, while the social and cultural context or the collective consciousness from which these processes emerge, are largely ignored. This limitation was addressed with the emergence of social epistemology, which should not be conflated with the epistemology of social constructivism. The latter contains implicit empiricism, thus preserving aspects of the older dualism.

In the traditional regime, Descartes asserts that knowledge begins with the fact of the individual's thinking and with the self as the subject of that thinking. This perspective profoundly influenced subsequent philosophical and educational approaches by emphasizing the autonomy of the thinking subject and the role of introspection and logical reasoning in acquiring knowledge, which later shaped individualistic and rationalist trends in education.

Anything other than the subject can be known through logical processes and elaborations of its own mental content, independently of sensory or other experiential perceptions. For Descartes, the certainty of cognitive objectivity is achieved through logical abstraction. Consequently, the attainment of such knowledge is an individual, rather than a collective, endeavor. It is a subjective activity, even if based on logical reasoning and rules. This perspective was largely supported by Kant, who regarded logic as a sufficient tool for justifying knowledge.

Subsequent epistemological theories of empiricism placed great emphasis on the constructive activity of the subject in the process of cognition (the "logical constructions" from sensory data of the logical empiricists such as Mach, Avenarius, Russell, etc.). In these cases, constructs have been approached as a way of identifying and describing what is given in subjective experience, either of the individual or of the researcher, both in the form of sensations and in the form of measuring instruments and devices. In other words, from this perspective, constructive activity in cognition is justified to the extent that it serves to understand what is empirically given. This kind of active constructing process also becomes central to constructivism, ontologically, epistemologically and methodologically, though not exactly in the same way.

The view that there is nothing directly given in cognition, even in sensory experience, seems to have strengthened the constructivist perspective as a substitute for the empirically given (von Glasersfeld, 1995). If something cannot be empirically perceived, then it must be constructed. But the "myth of the given" should not be replaced by the "myth of construction." In cognition, reality is not given directly and completely, but it is perceived in fragments, while its understanding is extracted through an active and interpretative process. But, to extract something, one must have a means. Here, the means is the intensive activity of the knowing that includes observations, transformation of the environmental clues, the use of various measurement instruments, the implementation of experimental designs and, finally, the construction of scientific theories. It is a constantly interactive process in which understanding improves as the medium improves and vice versa. The above, even though are rather epistemic remarks from empirical sciences, should not be ignored in philosophical thinking and discourses.

In the 20th century, a culmination of a shift in interest from the individualistic to the social was observed regarding the origins and formation of knowledge (Cole, 1996; Vygotsky, 1978). This shift influenced educational practices by emphasizing collaborative learning environments and the importance of social interactions in cognitive development. Theoretical frameworks in social epistemology, such as those proposed by Vygotsky, further highlighted the role of socio-cultural contexts and community engagement in shaping how knowledge is acquired and constructed. The collective approach aimed to provide social explanations, either historical or sociological, for various phenomena related to knowledge, especially in science. Radical positions were led to claim that the above is supposed to be nothing more than beliefs or collective convictions, while the proposed explanations deliberately made no reference or claim to truth or even to the validity of such beliefs. Social constructivism, which was the primary vehicle for this pursuit, not only underestimated the existence and influence of physical entities and processes as independent and self-existent but went so far as to deny them (Latour & Woolgar, 1986). For instance, in the context of scientific discovery, social constructivists might argue that concepts such as gravity or atomic structure are not objective realities but rather constructs shaped by the cultural and historical conditions of scientific communities. This perspective prioritizes the social processes behind knowledge production, often dismissing the notion of an independent, material world. According to this radical view, reality—whether physical, social, or cognitive—is constructed, this time socially.

Constructivism ascended as scholars grappled with the problems and difficulties posed by empirical and rationalist descriptions of knowledge that maintained strong Cartesian distinctions between the knowing subject and the cognitive object (Mascolo & Pollack, 1997; Riegler, 2001). For many scholars, the conflict is not, as it is often portrayed, about the merits of individual epistemologies and their expressions. Rather, the essence of the debate is constituted much more in the dipole of objectivism versus subjectivism. This controversy runs through the history of epistemology at least since the 17th century and takes the dilemma to the level of cognition and knowledge: whether cognition deals with a reality that exists independently of it, or with facts of one's own consciousness (Bredo, 2009). Contemporary subjectivist trends are radical and social constructivism, with an extension to postmodernism. The term 'subjectivist' means that knowledge is based on the experience, direct or indirect, of those who are seen as producing or questioning knowledge (Guba & Lincoln, 1994; Moore, 2013).

Particularly in recent decades, the epistemologies of radical and social constructivism have played a key role in debates focusing on social and educational theory. Proponents of both radical and social constructivism value knowledge for its usefulness, or more precisely for its viability, and avoid as irrelevant the assumption that knowledge is about (any) reality. Both versions assert that people, including scientists, do not discover reality but instead construct their understanding of the world through experience—either intersubjectively, in the case of radical constructivism, or socially, within communities, in the case of social constructivism. This has an internal connection with early forms of empiricism, since knowledge is acquired through experience, directly or indirectly. Theories that are not based on experience, especially lived experience that is not based on direct sensory data, are of no value to a constructivist (Bunge, 1993; Popper, 1963/2002; Slezak, 1994).

Nevertheless, concerns persist that constructivism, especially the social version and the postmodern turn, leads to relativism by claiming that no interpretation of reality is privileged and thus all interpretations are equal and valid (Phillips, 1995). The above descriptions of knowledge inevitably drift towards relativism because they question any objective basis on which knowledge can be formed, except the positions of the individuals who produce knowledge and are intertwined with their particular social interests (Moore, 2007).

For many scholars, the focal point of the objectivism-subjectivism controversy has been philosophical realism. Philosophical realism fosters the ontological position that the external world exists independently of sense experience, the will, or any beliefs (Hacking, 1999). The question of the possibility of knowing the world touches on epistemological reflection. It is therefore possible to support the first position in the existence of an objective world and not accept the counterpart. One can argue that material (physical or social) objects exist externally, objectively, but cannot be known, except, perhaps, their appearance, their phenomenological expression. Or one can argue that the world is intelligible because it is constructed subjectively and/or intersubjectively. Consequently, realism is opposed to subjectivism in all its forms. However, realism as an ontological viewpoint should not be identified with any form of materialism. This is because, apart from assuming an objective reality, realism does not necessarily recognize the primordial materiality of the world. If realism is steered to the rejection of the material nature of the world and the adoption of other existences (e.g. the objective spirit according to Hegel), it can logically lead to what is called objective idealism (Pinkard, 1994).

Similarly, realism should not be confused with empiricism, as both differ significantly in their epistemological underpinnings and assumptions about the nature of knowledge and reality. While realism posits that the external world exists independently of perception, empiricism confines knowledge to what can be directly experienced through the senses, thereby incorporating a subjective dimension. This distinction highlights realism's focus on objective existence, in contrast to empiricism's emphasis on observable phenomena.

The ontological thesis of realism can be restated as follows: there are things in themselves (*Ding an sich*). Its epistemological companion can then be restated as follows: we can know things in themselves, the intelligible (not just as they appear to us, the phenomena). It is argued, and rightly in our view, that these two positions are presupposed in all scientific inquiry, often implicitly. For example, when a new hypothesis or theory fails rigorous empirical tests, it is rejected because it does not fit the facts, because it is not realistic. But this may not be the end of the story. First, the results of the tests may turn out to be wrong. Second, if they are true, one can try to modify the original hypotheses or theories in the hope of achieving more accurate, realistic representations. If this attempt fails, one can try to construct entirely different representations or even try a different method. Either way, this is the process of approximating objective truth.

In general, what the different approaches share is a neglect of ontology or a tendency to downplay its significance. Beyond focusing on the subject and the potential of language, they lack a systematic effort to describe and explain reality. As a result, questions of knowledge are reduced to epistemology centered on the knowing subject. The debate revolves around the model of the subject, not the model of knowledge itself, which remains rooted in the subject. Any consideration of the ontology of either reality or its representation is notably absent.

Aiming to contribute to the long-standing debate about the content of philosophy of education, we advocate for the introduction of complexity theory as a new perspective in the field. (Hager & Beckett, 2024a, 2024b; Lemke & Sabelli, 2008; Mason, 2008a, 2008b; Morrison, 2008; Radford, 2008). Complexity Theory, which is founded on mathematics, describes and interprets nonlinear dynamical systems and, with its methodological advances, comes to question the ontological and epistemological assumptions of traditional science and, by extension, the theoretical knowledge produced in the given context. It introduces a different philosophy—ontology and epistemology—of the real world, which inevitably influences relevant fields, such as philosophy of education, but most importantly offers an alternative worldview that is more responsive, descriptive, interpretive, and generally consistent with the ontology of social reality.

The development of the sciences, social sciences in general and education in particular, has been profoundly influenced by philosophy, and ideas about human systems are often rooted in a mechanistic conception of the world. Descartes's contributions were pivotal in this regard. The period during which Descartes sought to address fundamental, primordial questions was characterized by an intense effort to systematize the methodology of the natural sciences, with a central interest in the collection of data and their mathematical, quantitative description and representation, with the aim of understanding the behavior of objects and material reality. Knowledge of geometric form, mass, motion, and other measurable quantities seemed sufficient to understand and explain the relationships between objects. However, the realization that material objects alone possess these properties, while other qualities such as taste or emotion lack measurable characteristics, played a crucial role in the later development of epistemological and methodological thinking in the social sciences. This limitation within the natural sciences led to a corresponding distinction between the theoretical objects of science and the real objects of the world (Matthews, 1992, 2009).

For Descartes, the machine served as the basic metaphor for understanding the natural world. By embracing the mechanistic view, scientists adopted a simplified understanding of the relationship between parts and the whole, as well as of causes and effects (Hollingsworth & Müller, 2008). This metaphor was eventually generalized, albeit unintentionally, on the social level as well, as a view of the whole world, as a description of how it works, and as a "recipe" or suggestion for how to study it.

As mentioned above, Cartesian dualism gave rise to several complicated, even seemingly intractable problems, at both ontological and epistemological levels. Descartes conceptualized the world as a clockwork mechanism, turning this operation into a cornerstone of the scientific method, which combined logical abstraction, quantification, and a reductionist view of science. Methodological reductionism has emerged as a dominant tool throughout the history of scientific achievement. However, there is a broad consensus regarding reductionism and the following contradiction: although the inadequacy of such an assumption has been methodologically highlighted, it still exists in tandem with analogous ontological and epistemological and influences the research strategy in contemporary science (Mazzocchi, 2008, 2016).

Based on the above, the formulation of the scientific procedures is based on respective ontological assumptions concerning the parts and the whole. According to this framework, the best way to scientifically study an educational system—such as a classroom or a school—is to focus on its constituent parts, studied separately and in isolation. An understanding of the whole is then extracted from the reconstruction of the parts and, more importantly, from their simple aggregation. Studying a system in this way implies that the explanatory power attributed to the parts is sufficient to comprehend the whole system, and that the properties of the parts in question remain unaffected by their environment. However, this model is only applicable to closed or isolated systems, where interactions with the environment are absent, minimal, and/or linear, while environmental and emergent relationships are not central to the operation of these parts.

The approach that dominated the study of reality was therefore reductionism, including the social sciences realm. The premise was the representation of a social structure, as a set of subsystems coexisting with each other, starting from individuals organized into groups, groups into larger sets, etc., up to the whole society. Therefore, the behavior of larger interacting systems could be understood by analyzing the elements separately, by studying individual, isolated factors. This perspective is positioned in the search, recognition, and clustering of universal laws (Heylighen et al., 2017) for all levels of reality. While reductionism may be applicable to simpler systems, its utility is severely limited in both the physical and social domains (Byrne, 2005, 2014).

The Newtonian worldview continued this reductionist tradition. For Newton, the universe was rational and mechanistic. Predictability, causality, linearity, universality, stable patterns, evolution without discontinuities, jumps or reversals, stability and controllability were the essential and basic, non-negotiable features of the world (Kallemeyn et al., 2020). The representation of the universe, in short, is consistent with the image of an organized mechanism in equilibrium, however complicated, of a rational, closed, controllable and mechanistic system, amenable to simple scientific discoveries and laws (Morrison, 2008). In Newtonian science, a clear distinction was made between what was considered simple and what was considered complicated: there was no hesitation in calling Newton's laws of motion, the laws of ideal gases, or chemical reactions "simple." On the contrary, biological processes, let alone human activities, could be called complex. But even in this case, the goal of normal science was to discover an underlying simple level, even in complex systems. This level would be the carrier of the deterministic and time-reversing laws of nature: the future and the past would play the same role. However, this fundamental simple level remained and remains elusive (Hmelo-Silver & Pfeffer, 2004).

The reason for the pervasive influence of this philosophical thought is that the mechanistic conception, in addition to its simplicity, retains certain attractive features. These include the image of coherence and its apparent completeness, as well as the expectation of laws that ensure certainty. At the same time, the development of mechanics, the science of motion, and later of electricity and magnetism, was followed by the invention of technical devices and the industrial production of goods, products, and commodities that changed and profoundly transformed the environment, society, and facilitated everyday life. Thus, the achievements and recognized value of "reductionist" science left little room for philosophical critique. Its effectiveness in describing simple and separable systems fostered the belief that it could be applied successfully to more complex phenomena found in socioeconomic, psychological, and cognitive systems.

Recognizing that the epistemology of education requires a robust account of social reality and the social nature of knowledge, one that remains compatible with confidence in the concepts of truth and objectivity (Bakhurst, 2020), we propose the perspective of complexity as a means of transcending dualisms and apparent distinctions. Examples of such dualisms include the division between subject and object; mind and body; theory and practice, which are frequently viewed as isolated or opposing entities rather than as mutually constitutive. The perspective of Complexity Theory seeks to integrate these polarities, fostering a more holistic and dynamic understanding of reality.

The Emergence of Complexity

Complexity theory (CT) stands as a counterpoint to traditional science, which is rooted in a reductionist, mechanistic, linear and in any case limited and fundamentally erroneous conception of reality. The philosophical framework of CT ascents from its fundamental form, which is a mathematical theory that uses differential equations to describe systems with specific ontological properties. It comprises two main branches: chaos theory, which pertains to systems that evolve over time, and fractals, which describe spatial structures. The following discussion focuses on the philosophical consideration of the positions, concepts, and viewpoints that derive from this theory, which presents a perspective clearly opposed to Newtonian science.

As we already mentioned, CT offers an alternative and integrated view of the cosmos, a worldview that conceives and treats reality as a dynamic, interconnected network of parts, which are in continuous interaction that determines the process of becoming (Cochran-Smith et al., 2014). Complexity functions as a mode of existence of reality, acting as a unifying factor between the natural and social sciences. Its main advantage is that it provides us with qualitative and quantitative methods, enabling us to specify more complex phenomena or processes that were previously addressed in more abstract, often philosophical terms (Maaita & Gkevrou, 2026). An example of such a philosophical approach is dialectics, which describes more complex behaviors and phenomena in nature, society, and human beings. It is also a broader descriptive framework within which researchers incorporate several new scientific premises that share the idea of the coexistence of randomness and some kind of causality, but with system dynamics as the prevailing protagonist. These elements define a situation originally called chaos, resulting from the dynamic interaction of parts and characterized by an apparent disorder coexisting with distinct forms and order, an ontology that involves change. From chaos, new structures emerge that cannot be reduced to the properties of the individual constituent parts of the system (Clark, 1997).

A critical feature of these systems is that outcomes cannot be predicted in the traditional sense, as they arise from self-organization and dynamic interactions. Order is not imposed externally; rather, it emerges internally from within the system itself. As such, order and randomness, chaos and causality are deeply interconnected and should be studied together (Steenbeek & van Geert, 2013; van Geert, 2011). This is evident in evolving systems with all opposing or competing processes or any pair of opposites, but whose coexistence and conflict in a context of competition and cooperation simultaneously form unique outcomes (Kelso, 1995).

Literature distinguishes between simple or even complicated (not complex) mechanical systems that behave in a linear and predictable way. A complex system, on the other hand, consists of numerous interconnected parts and it is characterized by the nonlinear dynamical interactions of the individual components. Simultaneously, the role and contribution of time to the evolution of things is emphasized and recognized as a crucial factor. Interactions are multiple, and it is the multiplicity of interactions over time, involving feedback loops between hierarchical levels, that produces effects. Causality in this situation cannot be reduced to one or a limited set of factors, nor can the outcome be described simply as a linear sum of the components (Haggis, 2008; Serrat, 2017). Therefore, the behavior of a complex system cannot be predicted by isolating and studying its individual parts.

Complexity theory embraces the concepts of evolution, adaptation and development, asserting that change is the rule while stability is the exception. This perspective challenges simplistic, linear models of cause-and-effect, and reductionist approaches to understanding phenomena, replacing them with nonlinear and holistic approaches that focus on relationships evolving in time.

The evolution of a dynamic system, as a product of interactions over time, is sensitive to initial conditions and parameters. Slight differences in these conditions can produce vastly different outcomes, underscoring the uniqueness of each dynamical system and combinations of interactions over time will produce different trajectories, different histories for each case (Haggis, 2008). The emergent properties of complex systems arise from the nonlinear dynamical nature of the evolving process, where each step depends on the previous one, and the role of random fluctuations in the processes is important. That is, the seemingly insignificant "accidents" in its history cannot be ignored and may have determinant impact (Perrow, 1999). Systems evolve through internal dynamics, driven by self-organization mechanisms, rather than external intervention (Prigogine & Stengers, 1984). These systems, known as Complex Adaptive Systems (CAS), show adaptability to environmental changes and exhibit the ability to learn from past interactions, shaping future trajectories.

Complex adaptive systems are defined as interconnected networks of multiple elements, entities (or agents) that exhibit adaptive behavior in response to both environmental and systemic changes. The collective performance or behavior of the system appears as nonlinear and dynamic, a function of the large number of actions or activities performed in parallel by interacting parties (Pathak et al., 2007). Thus, the notion of self-organized adaptation denotes the property that allows systems to change and evolve over time in response to feedback and changes in the context of the system and the environment. This means that a CAS has memory and the ability to learn from past responses and changes, thereby influencing and shaping its current and future trajectories.

CASs exhibit different levels of hierarchical complexity, where properties in a level are emergent phenomena, due to interactions at lower levels of the system (Hager & Beckett, 2024a, 2024b). Unlike simple mechanical systems, CASs can possess multiple equilibrium states. It is imperative to mention that for the underlying processes, the ergodicity assumption does not hold, that is a dynamical system does not visit all possible points in the phase space. In the mathematical language of complexity, it is said that it exhibits memory, returning to selected regions or states called attractors. Complex dynamical systems operate far from equilibrium, create a history, and change state over time, often in nonlinear ways (Cilliers, 2000; Serrat, 2017). The phenomena of emergence in CAS emphasizes that complex dynamic courses are those that produce novelty, they are the creative processes.

Emergence, a central concept in CAS, refers to the novel phenomena that arise from the dynamic interactions within the system and suggests that, given a sufficient degree of complexity in a particular environment, new and, to some extent, unexpected properties and behaviors emerge in that environment. This process is creative, driven by the capacity for adaptability and endurance, and is characterized by increasing connectivity, feedback, and interdependence (Richardson & Cilliers, 2001). Emergence and self-organization are intertwined; self-organization is a prerequisite for the emergence of novel states.

The concept of self-organization has sparked considerable debate, particularly in ontological terms. In the context of complexity, it occupies a central position with explanatory power. Self-organization is central to the causal interpretation of phenomena such as bifurcation, hysteresis, and discontinuous change (Nicolis & Nicolis, 2007; Nicolis & Prigogine, 1977). The theoretical descriptions of the emergence of dynamical structures laid the philosophical foundations for applying complexity theory to biological systems and, later, to social systems.

This theoretical perspective requires and counts on an interdisciplinary understanding of reality, insofar as complex open systems with dynamic transformations, while it pursues the unity of the sciences based on a single ontology of the world itself, without ignoring the specificities of each field. This is understood and accepted all the more when we refer to social reality or to psychological, educational and cognitive phenomena and processes, where human activity and its influence are decisive. In essence, complexity theory is concerned with describing and explaining change, but to the extent that it can claim the name of meta-theory with a unifying role, it is established precisely because of the revolutionary way of thinking it introduces, which is inherently different from that of traditional science (Heylighen et al., 2017; Stamovlasis, 2016), and its importance as meta-theory have been mentioned towards relational perspective in developmental and dynamic systems (Overton, 2007, 2013, 2014; Overton & Lerner, 2014).

Most importantly, in the traditional framework, education assumes that the process of self-regulation will lead the system to a single equilibrium position, which is consistent with the mechanistic view of reality, and this position is rather teleologically determined. The question is what determines the single equilibrium position and whether this view is consistent with reality. Such epistemological questions are not discussed, and in the field of education the problem is considered solved by the prevailing assumptions. For development, the determination of the equilibrium position in the traditional framework is reduced to individual specifications e.g. the genes, and this is an irreconcilable compromise, since the methodology followed with the mechanistic model of the worldview does not foresee the emergence of another equilibrium position. The clash between the traditional reductionist view and complexity theory is well known, where dynamical systems forecast and explain the unexpected developmental shifts of children as a result of the nonlinear interactions of individual and environmental factors and self-organizing mechanisms (Molenaar, 1986).

Learning and Development as Complex Adaptive Systems

Complexity theory, like any theory, is formulated at a high level of abstraction. When applied to specific domains, variations in conceptualization and functional definitions may arise. However, certain notions, such as pattern formation, robustness/resilience, dynamics, and autonomy, remain consistent across applications. The core concept autonomy refers to the control of the mechanism behind the process and its independence. As the prefix "auto-" implies, the concept denotes a process without central control.

In this view, processes that philosophy of education examine, such as learning and development (cognitive, intellectual, emotional, social, etc.) are thought to be guided by self-regulatory mechanisms which explicitly involve interactions among individual components. Within CAS perspective the notion of self-organization becomes a key issue and a binding element for alternative approaches such as Piaget's and Vygotsky's theories. Thus, human development, evolving as an individual process within environmental contextuality, is not a linear, deterministic progression that can be approached and predicted by the machine metaphor.

Advances in research on human brain function and cognition have already made a shift towards complexity theory, and models based on CAS have provided empirical evidence, supporting the new paradigm (Kelso, 1999; Freeman 2000). Thus, philosophical inquiries regarding the nature of cognitive, mental, and psychological processes are reasonably abandoning the machine metaphor and fostering the complex adaptive systems view. This approach necessitates representing the examined system as a network of interconnected elements or agents, which exhibit adaptive behavior in response to changes in both the environment and the system itself. The collective performance or behavior of the system emerges as nonlinear and dynamic, driven by multitude of actions or activities occurring in parallel through interacting parties (Pathak et al., 2007). Therefore, the outcomes of these long-term processes result not from a single or a few-factor linear effects, but from the local and temporal contributions of many factors, which operate nonlinearly across different timescales.

Philosophical endeavors can be grounded in descriptions adapted to the general representation of the system under investigation. Consider, for example, the nature of knowledge and belief systems. In an individual mind, epistemic cognition, subjective thought, perception, epistemic beliefs, and scientific views are not detached and isolated components; rather, they are interconnected elements that interact and influence each other. Simultaneously, they are linked to elements of the social or cultural environment in which they develop. This results in couplings and assemblages of internal and external systems. The internal subsystems refer to the cognitive and psychological aspects of the subject itself, while the external ones are embedded in the environment, including communities of everyday life, and institutionalized sources of scientific knowledge. Consequently, a subject's developing epistemic cognition becomes a network of interdependent psychological and behavioral components.

Interdependence suggests that the related components cannot be treated as independent variables, as in the traditional epistemological and methodological framework happens. The holistic perspective, therefore, asserts that a subject's current epistemological understanding depends and, on the environment, such as the academic context, the level of collective understanding, and the science view (van Geert, 2014). This view does not claim a causal relationship between components but instead introduces the concept of interdependence as a source of causality, thus shifting the conceptualization of causation from the traditional linear model to a holistic framework that cannot be reduced to a singular factor. This representation is not merely a metaphor but serves as the foundation for methodological advances in scientific research, such as network analysis. This indicates an important element contributing to the unification of philosophy and contemporary science, an issue that is certainly pursued.

A key advantage of the Complexity Theory perspective in education and educational research is its ability to offer a more credible representation of the processes at work within these systems. Consider the system of human semantic memory and conceptual change as the outcome and/or the learning process itself. The ontology of CAS provides a foundation for developing theories that incorporate a rational mechanism of change. In cognitive processes, when a concept is activated, the activation spreads to neighboring concepts or nodes in the conceptual network, priming them and making them easier to retrieve or understand. Thus, in this context, each concept is understood as an associative network of meaning. Moreover, in cognitive processes, mental resources are activated in parallel or in series, and their presence can be viewed as an analogous network of cognitive operators, which is interwoven with conceptual network, with dynamical interactions that might alter the conformation and the structure of the latter, leading to conceptual change and specific learning outcomes. This is an explicit Complex Dynamic System (CDS) approach to understanding the mechanisms of learning, where processes of activation and operation of cognitive resources can enhance or impair conceptual systems over time (Siew et al., 2019).

A similar worth discussing application of CDS concerns conceptual, linguistic and semantic systems. The basic assumption is that knowledge, as represented in the human mind, is highly structured in a network configuration, and that this organization affects how words are recalled, pronounced, recognized, understood, or generally processed. Therefore, identifying patterns of linguistic association can provide insights into the structure of the mind and the processing of knowledge, if the appropriate cognitive methods and tools are employed.

Insofar as language is the means by which the world representations are constructed in the mind, and in light of the above, the meaning, representation, and properties of concepts are definitely subjects of study in complexity theory. Just as multitude sentences carry meaning, so do the network representations. Meaning and representation are the product of the language function. Concepts are viewed as complex, organized semantic entities, associations of meanings that are dynamic by nature. In the semantic mapping of concepts through network structures, concepts act as nodes, while relationships between them are defined by edges. Learning occurs when the characteristics of the relationships between these nodes are modified. For example, when a new linking leads to disorder or disturbance, e.g. a cognitive conflict, the strength of the connection is modified, reduced and eventually restructured. A given activation at an input node spreads throughout the network, modifying the weights of the links and making subsequent interactions more efficient. The network thus learns by organizing itself and recording the most efficient paths and consolidated states in its "memory" (Hardy, 1998).

To gain a deeper understanding of the function of language in the mind, one must consider not only the connections between concepts or the transformation of concepts themselves, but also their transformative effect on other concepts. An understanding of a word is constructed based on both existing concepts and the characteristics of the context. The result, the newly signified concept, represents a new order or state of equilibrium resulting from specific cognitive conditions. Extending this, it seems logical to assume that concepts continue to evolve and change throughout an individual's lifetime. Thus, conceptualization of the process of forming or refining concepts reflects the mind's functioning as it attempts to understand and express its experiences, reality, etc. On a substantive level, thinking is a creative act, in which certain concepts are used to form other concepts. Concepts, therefore, are not only mutable, involved in changing processes, but also generative of new processes; they are transformative, rather than simply subject to transformation. Consequently, concepts are embedded in a dynamic thought process that continually modifies them, while simultaneously affecting dynamic changes within the broader semantic network. The above theoretical description, within the complexity theory framework, replaces the old architecture metaphor that prevails in the traditional representation of knowledge, where concepts are arranged as bricks in a wall and conceptual change is the restoration of the wrong concepts or misconceptions with the correct ones.

To the extent that concepts range from simple, basic ideas to more complex, abstract notions, the set of concepts possessed by an individual constitutes or reflects that individual's idiosyncratic worldview. These meanings form the foundation of one's sense of self and understanding of others and the world. The meaning of any concept depends entirely on its relations to other concepts, and the structure of these relationships is constantly subjected to modification and change. This creative and complex process of constructing representations, although not universally valued by the entire scientific community, has, in social sciences mainly, fostered the misleading view that language and/or thought determine and construct reality. This misconception explains the rise of radical social constructivism.

Consider modern cognitive science, which posits that cognition involves processes through which the brain processes information, receives stimuli from the external world, constructs images, interprets and explains the above, and so on. Cognition, perception and thinking are better understood when the self and the world are considered parts of the same system, where information is provided and processed. This view challenges classical mental representations by proposing a theory of dynamic cognitive systems grounded in CAS. In this context, cognition is seen as embodied manifested through interactions with surroundings. Perception is not an "ideal object" existing solely in the inner world of consciousness but is rather a dynamic process. It is not merely a unidirectional linear procedure of empirical impressions or external influences of the outside world on the sensory system, but rather an interaction between what is perceived and the external world, consistent with CAS behavior (Bergson, 1911; Whitehead, 1929/1978).

Our thesis is that consciousness naturally adheres to Complexity and nonlinear dynamical systems and is shaped continuously through interaction processes that include both internal and environmental factors.

The emergence of consciousness and the development of cognition, which differentiated humans from other living beings, can be understood historically through the coevolution of the brain and adaptation to the environment. This process integrated several key changes, including the freeing of the hands, the use of tools, the gradual transition to upright walking, and the development of explicit intentionality directed toward environmental control and survival. Moreover, the systematic invention of symbolic systems for communication and the development of human language (Kotchoubey, 2018) played a crucial role in the evolution of a highly adaptive and creative cognitive system, as reflected in the collective achievement of human civilization.

Integrating the above understanding of cognition as activity into the framework of dynamic cognitive systems, it follows that cognition is not something that occurs exclusively within the knowing subject but is a dynamic process in which the psyche, the body of the knowing subject, and the surrounding real world are three aspects of a single activity. The Cartesian opposition between the inner and the outer is thus eliminated.

The study of collective cognitive and scientific activity as socially and culturally determined, which, currently, has gained considerable interest, can be enlisted within the framework of complexity theory. The individual activity is embedded in the collective exertion, where both are parts of a whole that could be viewed as CAS, a historically evolving dynamic system. Individual cognition is interpreted as a component of the collective cognitive process, but this process is not reduced to the individual. Reductionism, once a dominant notion, is now considered invalid in complex dynamical systems. As a result, this perspective is shifting the philosophy of education, where theories of social or psychological processes, such as development, teaching, learning, cognitive functions of the brain and interactions in the social and educational environment are reconsidered (Piaget, 1971; Vygotsky, 1978).

Traditionally, while the term "dynamic" has been used extensively to characterize such processes, the persisting mechanical system view has failed to provide a coherent epistemological position. In addition, the customary analytical approaches in empirical research that employ models expressing the outcome of processes, such as cognitive tasks or child development, as the linear sum of the individual contributing components, have failed also, betraying reductionism. In contrast, nonlinear modeling has provided empirical evidence for the operation of complex adaptive systems within educational contexts, such as problem-solving and decision-making (Stamovlasis, 2011; Stamovlasis & Vaiopoulou, 2017). These studies have highlighted the limitations and the drawbacks of traditional theories and questioned their epistemological assumptions, especially the computer metaphor for the mind and the mechanical view of human processes. Complexity theory suggests that human functioning operates far from equilibrium as a nonlinear dynamical system, and point out that processes, such as learning and development, are non-ergodic (Grasman et al., 2009; Stamovlasis, 2011; van Geert, 1994). The outcomes and achievements are not predetermined merely by some initial conditions (e.g. genes), as was argued in an earlier controversy (Fodor, 1980; Molenaar, 1986). It is the nonlinear dynamical character of the processes, which allows for the emergence of new structures that cannot be traced back to pre-existing capacities.

Education addresses phenomena and systems of remarkable complexity, where self-organizing processes play a central role. The characteristics of CAS with interaction networks and self-organization mechanisms are the collective systems that can produce innovation. This includes creative behaviors demonstrated in thought, philosophy, scientific inquiries, or cultural contexts, and moreover in resolving the most complex and challenging problems of our time. On the contrary, the deprivation of the fundamental ontology, which could induce nonlinear dynamics and emergent phenomena, works counterintuitively and inhibits creative behavior.

Social structures and relations are emergent entities that result from historical human action. Historicity, in this sense, refers to the dynamic development of systems over time. Social relations and their development depend on time and space, which, in turn, shape human behavior. In complexity theory view, organisms or social structure, respond to the environment by adapting to it, but they also influence the surroundings, via an iterative process that results in dynamic relationships and continuous change.

The implications of the shift towards complexity theory are radical and transformative. Complex Dynamic Systems (CDS) facilitate interdisciplinary endeavors and the integration of human intellectuality by reconciling different ways of understanding reality. It offers a framework that transcends the historical separation between the "hard" natural sciences and the human sciences, suggesting that a unified approach to philosophy of science is both possible and desirable. The pursued unification is not denial of the peculiarities in each domain, but a synthesis and amalgamation of all philosophical -ontological and epistemological- presuppositions for understanding reality. The complexity perspective is groundbreaking for another reason. It can provide the link between universality and individuality, drawing on the latest developments in each discipline.

Discussion and Concluding Remarks

Complex dynamic systems, as exemplified by the phenomena of the evolution of life, cognition and consciousness, exhibit non-ergodic behavior that generates process memory and historicity (Koopmans, 2015). The existence of life is attributable to non-ergodic, creative processes, which also characterize human behavior and experience. Consequently, dialogues in the philosophy of education should include the ergodic hypothesis as a crucial matter when reconsidering the issues discussed in this paper.

Educational processes can broadly be classified into two general categories. First, there are tasks of deductive type, where subjects engage in algorithmic procedures, such as, when novices practice mathematical or linguistic exercises, develop automaticity, or memorize historical facts. The outcomes or the results in these processes are already known, and the steps are predetermined, while the algorithm does not produce new information.

In contrast, processes of inductive type (inductive processes), whether cognitive or behavioral, do not follow a predetermined path; instead, each step determines the next. These systems follow a nonlinear dynamical process. The information that does not preexist in the initial data, is in fact generated during the evolution of an iterative and recursive process (Nicolis, 1986). In other words, such processes consistent with the nature of complex adaptive systems (CAS), are creative processes.

For philosophy of education, this theoretical remark offers valuable insights into understanding educational systems. A creative system that innovates, rather than merely "producing" outcomes through algorithmic processes like a machine or a chatbot, aligns with the principles of a complex dynamic system. Applying this theoretical premise has significant implications across disciplines, including education, administration, politics, economics, geopolitics, law, and philosophical thought, aiming for rejuvenation of its representations of reality within the new worldview.

In educational contexts, problem-solving and conceptual change methodologies should not conceive human cognitive systems as mechanical and deterministic. It is an epistemological fallacy to adopt the view that defines learning as the simple replacement of a child's misconceptions with the correct ones. Instead, within CAS perspective, teaching, learning and development should be designed to mimic nonlinear dynamical processes, where the outcome can emerge via the self-reorganization of conceptual networks (Stamovlasis, 2011). The dynamic process perspective in learning explains why collaborative learning is more effective than traditional frontal teaching. Nonlinear dynamics in interactive environments guarantee creativity, whereas deductive algorithmic processes appear productive, but inhibit innovation.

A similar argument applies to management at the level of schools or organizations. There is no need to reiterate that educational systems are complex and adaptive. If schools and classrooms are to be understood as spaces of complexity, then the certainties that the reductionist model seeks to offer, along with the stakeholders' expectations regarding learning and the control of outcomes, are significantly undermined. Education becomes a much more open-ended endeavor, with an emphasis on a more imaginative and creative response. This conceptualization implies a much greater degree of professional freedom for the teacher and a less strictly controlled accountability system (Radford, 2008)

These limitations have been recognized and addressed through innovative proposals in teacher education (Cohen & Gilead, 2023; Koopmans, 2023b). Adherence to a mechanistic worldview often fails to achieve fundamental goals such as social equity, justice, and environmental sustainability (Koopmans, 2023a). Interventions designed with mechanistic assumptions of society overlook essential aspects of the system's ontology. Feedback mechanisms within networked structures featuring nonlinear interactions can yield outcomes contrary to intended goals. This vulnerability lies in the dominant representations of reality, which align with a mechanistic model, promoting theories grounded in linearity and reductionism.

Viewing social phenomena as complex dynamic systems offers a framework to integrate seemingly opposing scientific perspectives, beginning with the unification of epistemological positions and assumptions. But it does not stop there. Science is understood not only as a stochastic observation of the world, but also as a set of social practices with profound implications for the transformation of the social world. The Complexity Theory perspective, thus, holds the potential to induce the rejuvenation of philosophical thought and the epistemological reconstruction of education.

Overall, Complexity Theory is not merely a new set of terms, but a fundamentally different way of thinking that treats creativity, uncertainty, and continuous change as core features of social systems. Adopting this perspective requires shifts in how we think, conduct research, and practice education, ultimately strengthening adaptability and innovation.

Finally, this shift in perspective has already been recognized at empirical and methodological levels within educational research, and it is also increasingly acknowledged at the philosophical level, where a more unified view of human and social reality is being developed (Gkevrou & Stamovlasis, 2025).

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