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Three Generations of Complexity Theories: Nuances and ambiguities

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Abstract

The contemporary use of the term 'complexity' frequently indicates that it is considered a unified concept. This may lead to a neglect of the range of different theories that deal with the implications related to the notion of complexity. This paper, integrating both the English and the Latin traditions of research associated with this notion, suggests a more nuanced use of the term, thereby avoiding simplification of the concept to some of its dominant expressions only. The paper further explores the etymology of 'complexity' and offers a chronological presentation of three generations of theories that have shaped its uses; the epistemic and socio-cultural roots of these theories are also introduced. From an epistemological point of view, this reflection sheds light on the competing interpretations underlying the definition of what is considered as complex. Also, from an anthropological perspective it considers both the emancipatory as well as the alienating dimensions of complexity. Based on the highlighted ambiguities, the paper suggests in conclusion that contributions grounded in contemporary theories related to complexity, as well as critical appraisals of their epistemological and ethical legitimacy, need to follow the recursive feedback loops and dynamics that they constitute. In doing so, researchers and practitioners in education should consider their own practice as a learning process that does not require the reduction of the antagonisms and the complementarities that shape its own complexity.

Keywords: complexity, epistemology, history of sciences, anthropology of knowledge, social critique

> [What is] complex cannot be summarised in the word complexity, brought to a law of complexity, reduced to the idea of complexity. Complexity cannot be something which would be defined in a simple way and would replace simplicity. Complexity is a word-problem and not a word-solution. (Morin, 1990, p. 10, free translation)

Introduction: Complexity versus Complexities

In 2002, the US Department of Education asked the Washington Center for Complexity and Public Policy to describe how 'complexity science' was being used in the

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federal government, in private foundations, in universities, and in independent education and research centres. The Center's ensuing report provided a broad overview of the 'complexity science' landscape around the country (Washington Center for Complexity and Public Policy, 2003), revealing the increasing recognition given to theories informing the idea of complexity. At the same time, it also conveyed some misleading views probably representative of a trend: 'Complexity' considered as a unified concept might appear to be progressively reified. Reduction to a singular form ('complexity theory' or 'complexity science') could well lead to a neglect of the range of different theories that deal with the implications related to the notion of complexity.

Sharing the conviction of other scholars that the background of this notion has important potential with regard to contemporary developments in educational sciences (Ardoino, 1963/1999, 1998, 2000; Ardoino & De Peretti, 1998; Morin, 2000) this paper suggests the importance of a more nuanced use of the term, thereby avoiding simplification of the concept to some of its dominant expressions only. More radically, the position developed here suggests that within this notion reside deep ambiguities. In this context, tracing its history would seem a particularly relevant way to enrich the debate around its legitimacy and to reposition its meaning in a broader cultural landscape, including Latin traditions of research that often remain unknown in English-speaking countries. Following a chronological logic that discriminates among at least three contemporary generations of complexity theories (Le Moigne, 1996, 2001a), the paper aims to illustrate both their epistemic and their socio-cultural roots. Switching then from a historical perspective to epistemological and anthropological ones, the paper illuminates some competing interpretations underlying the definition of complexity. Scientific research is accordingly conceptualised as a learning process that requires not just reducing antagonisms and exploring complementarities, but also reviewing the contributions and the limitations that have shaped its own complexity (Morin, Motta & Ciurana, 2003).

Etymological Roots

The notion of complexity refers to the quality or condition of being complex. Adapted from the Latin expression '*complexus*' (14th century) and adopted from the modern French, the term derives from '*cum*' and '*plectere*', meaning surrounding, encompassing, encircling, embracing, comprehending, comprising. Originally denoting 'embracing or comprehending several elements', its use in English tended to be akin to the sense of 'plaited together, interwoven' (Simpson *et al.*, 1989/2005). Referring to things or ideas 'consisting of or comprehending various parts united or connected together' or 'formed by combination of different elements', 'complex' is often understood as a synonym either for composite and compound, or complicated, involved and intricate (ibid., para. 1). More specifically, it often characterises personality, society, feelings or thoughts that the mind finds difficult to comprehend and are not easily analysed or disentangled. During the past few centuries the adjective 'complex', denoting a plural of both quantity and quality, has conveyed various specific meanings: in mathematics (complex fraction, complex number); in linguistics (complex sentence) and semiotics (complex term); in music (complex note or sound) (Institut National de la Langue Française, 2005). As a noun, 'complex' refers to a 'whole comprehending in its compass a number of parts', especially interconnected ones (Simpson *et al.*, 1989/2005, para. 1a). Initially used in physiology (18th century), the expression migrated to economy, chemistry, biology and geometry. In the early 20th century, it appeared in psychoanalysis, in psychology (Gestalt theory) and in medicine (Institut National de la Langue Française, 2005). The terms 'complex' and 'complexity' are usually used as the opposite of simplicity. Their meanings pertain to the holistic, global or non-linear form of intelligibility needed to comprehend a phenomenon; sometimes they stress a pathological, dense, entangled dimension appearing as rebellious to the normal order of knowledge (Ardoino, 2000). Here is a probable source of the confusion between the words 'complex' and 'complicated', which are frequently but sometimes erroneously interchanged in their usage. It is important to keep in mind this rich semantic and conceptual background associated with the use of the notion of complexity in order to avoid the risks of reduction. Being aware of this diversity of use encourages us to explore the most salient meanings and uses, knowing that they are part of a semantic whole, richer than the sum of its parts.

Contemporary Genesis

In 1934, formulating his conception of a non-Cartesian approach to science, Bachelard was probably the first to legitimate epistemologically the role of complexity as an ideal for contemporary sciences (Le Moigne, 1996). If a Cartesian epistemology reduces complex phenomena to an analysis of their components, understood as simple, absolute and objective, a complexity-oriented epistemology favours understanding phenomena as part of a fabric of relations: 'There is no simple idea, because a simple idea ... is always inserted, to be understood, in a complex system of thoughts and experiences' (Bachelard, 1934/2003, p. 152, free translation). The recognition of complexity appears then at the origins of a new kind of scientific explanation which perceives simplicity as a specific provisional phenomenon. If complication refers to the idea of an intricate situation waiting to be disentangled, complexity supposes then the fundamental non-simplicity of studied phenomena (Ardoino, 2000).

Appropriation of the concept of complexity by the scientific community followed a decade later. In '*Science and Complexity*', Weaver (1948) considered the transformation of sciences since the 17th century and identified the successive emergence of three specific ways of conceiving the complexity of problems tackled by scientists. The first, identified later as the 'paradigm of simplicity' (Morin, 1977/1980), emerged from the 17th to 19th century. Grounded in the models offered by classical physics, it valorises objectivity, causal explanation, quantitative data and certainty. In this paradigm, complex problems are tackled by their reduction into more simple issues, explained or solved independently and successively. Since the second half of the 19th century, the discovery of disordered phenomena at various levels of organisation (the principle of entropy in thermodynamics, discontinuity in quantum mechanics, the explosive nature of stellar phenomena, etc.) contributed to a challenge to this paradigm of rational mechanics. Weaver identified a second paradigm that emerged at this period: one having to deal with problems of 'disorganised complexity'. Associated with the development of models proposed by the machinery of statistics and the theory of probability, this perspective included the consideration of disorder as an integral part of natural phenomena. In spite of their important contribution, Weaver observed that such frameworks did not allow the solving of some of the questions scientists still had to handle. Considering the contemporary problems tackled by biology, medicine, psychology, economy and political sciences as being too complicated to be interpreted through the models of rational mechanics, and not sufficiently disordered to be interpreted through the metrics associated with the second paradigm, Weaver identified them as problems of 'organised complexity', grouping in this expression 'all problems which involve dealing simultaneously with a sizeable number of factors which are interrelated into an organic whole' (Weaver, 1948, para. 3).

These initial distinctions enable the location of the main stakes related to the development of an original but dispersed body of research during the 20th century. From the 1940s until today, three generations of theories have emerged, suggesting a progressive shift from the study of 'organised complexity' to issues related to 'organising complexity' (Le Moigne, 1996), and thus reintroducing the fundamental uncertainties of the researcher as envisaged by Bachelard.

First Generation

Weaver recognised the value of two embryonic scientific trends that emerged from the Second World War—the study of electronic computing devices and the 'mixed-team' approach of 'operations analysis'. A set of new approaches—information and communication theories, automata theories, and cybernetics and operation analysis—can be found at the roots of these trends.

Mathematical Theory of Communication

Information and communication theories emerged with the mathematical theory of communication formulated in 1947 by Shannon (see Shannon & Weaver, 1963). Grounded in the practical issues raised by developments in the Bell telephone company and in his previous work on military encryption, Shannon developed a theory where an exchange of information (defined as 'binary digit' or 'bit') may be observed and measured statistically. Through concepts such as 'noise' and 'redundancy', the theory enabled the evaluation of the reliability of transfers of information by taking into consideration forms of disorder affecting channels of communication. Information theory contributed to explaining the phenomenon of organised complexity as the reduction of entropy (disorder) observed when a system (living or artificial) absorbs external energy and converts it into organisation or structures (order).

Automata Theories and Neural Networks

Based on previous work in formal and symbolic logic, and grounded in the contributions of Turing in the 1930s, automata theories were developed to deal with the body of physical and logical principles underlying the operation of any electromechanical device that converts information from one form to another according to a specific procedure. Automata are governed by operations whose principles can be perceived as a sequence of states which can be considered abstractly, as a set of inputs, outputs and rules of operation (Nelson, 1967). Automata theory contributed to a new perception of organised complexity when it was enriched by the research of McCulloch and Pitts on neural networks (1943) and by the work of Von Neumann on 'self-reproduction' (see below). Based on their neurophysiological research, McCulloch and Pitts offered a mathematical description of some features of the neural system. The concept of a neural network supposed a geometric configuration constituted by a large number of 'formal neurons' operating parallel basic operations. Enabling the description of complex operations engaged by automata, the concept of neural networks offered at the same time a powerful conceptual tool to represent a possible ontology of organised complexity.

Cybernetics

In 1941, as a consequence of research conducted by the US Army on the aiming of anti-aircraft guns, the concept of cybernetics emerged (from the Greek *kubernetes*, the art of governing), and from 1948 it designated a broad subject area concerned with 'control and communication in the animal and the machine' (Wiener, 1948/1961). Grounded in the development of information theory and automata theory, cybernetics introduced the concept of 'feedback' to describe how a system can operate by adapting itself to its environment following a pre-defined finality. Linking the idea of feedback to the concept of information, as theorised by Shannon, cybernetics offered a framework to represent the process through which information is assimilated and used by an organism to orient and control its own action. Following a behaviourist tradition, cybernetics grounded the understanding of organised complexity in the study of systems, conceived in a teleological perspective (instead of aiming to identify causes producing observed effects). From 1949, a series of ten successive conferences, known as 'Conference Macy', was initiated by Von Foerster, Wiener, Von Neumann, Savage, McCulloch, Bateson, Mead and Lewin. Despite the lack of a strong epistemological anchorage, these events contributed to the legitimacy of a research trend that provided a powerful pragmatic foundation to the idea of complexity (Le Moigne, 1996, 2001a).

Operations Analysis and Operational Research

The development of mixed-teams approaches, also known as 'operations analysis groups', was initiated during the Second World War by the British to answer problems of tactics and strategy. The procedure was applied to the Navy's anti-submarine campaign and the Air Forces:

> Although mathematicians, physicists, and engineers were essential, the best of the groups also contained physiologists, biochemists, psychologists, and a variety of representatives of other fields of the biochemical and social sciences … . Under the pressure of war, these mixed teams pooled their resources and focused all their different insights on the common problems … . It was shown that these groups could tackle certain problems of organised complexity, and get useful answers (Weaver, para. 14)

Progressively institutionalised as 'Operational Research' at the end of the war, this trend contributed to the emergence of a field of study focusing on the development of algorithms to tackle multidimensional decision processes involving uncertainty. Thus, problems of organised complexity with hundreds or thousands of variables were transformed and reduced into linear mathematical expressions which could be handled by computers (Beer, 1959; Churchmann, Ackoff & Arnoff, 1957).

Second Generation

Challenges raised by the Second World War thus accelerated the emergence and institutionalisation of the first body of research informing the concept of complexity. In the early 1960s, the notion was introduced for the first time in a significant American journal of epistemology (Simon, 1962). During the following decades, the development of large corporations, the progress of technology and the context of the Cold War provided the socio-cultural environment favouring the exponential development of new theories revisiting the idea of complexity.

Computer Sciences and Engineering Sciences

During the 1950s, with the extension of telephone networks and the development of large insurance companies, engineering sciences and computer sciences were confronted with the difficulty of conceiving and controlling broad systems perceived as complex ones. Using innovations introduced during the previous decade and the development of new generations of computers, various mathematical models were conceived (Ashby, 1956; Marcus, 1977), and the notion of 'algorithmic complexity' was established (Knuth, 1968). The perspectives opened by this research helped to reinforce an understanding grounded in a quantitative evaluation of complexity that considered, for example, the length of the account that must be given to provide an adequate description of a system (descriptive complexity), the length of the set of instructions that must be given to provide a recipe for producing it (generative complexity), or the amount of time and effort involved in resolving a problem (computational complexity) (Rescher, 1998). Allowing for comparison of the complexity of different systems, and based on mathematical measurement, these approaches contributed to providing instrumental definitions of complexity that bypassed the question of their epistemological legitimacy (Le Moigne, 2001a).

Management Sciences and Artificial Intelligence

In parallel with these developments, and intertwined with the institutionalisation of operational research and the extension of cybernetics to management (Beer, 1959/1970), the study of problems of organised complexity took root in the emerging sciences of management decision-making. Incorporating the contribution of game theory as formulated by Von Neumann and Morgenstern, the work of Simon on 'decision-making processes' in administrative organisations (Simon, 1947) and on 'heuristic problem solving' (Simon & Newell, 1958) contributed to the progressive emergence of an autonomous body of work designated as 'artificial intelligence' (AI). Located at the interface between economic sciences, computer sciences, psychology and logic, and grounded in heuristic methods of research, AI provided approximated representations of real situations more accurately than those calculated through operational research's algorithms. Being able to cope with any situation that can be represented symbolically (i.e. verbally, mathematically or through diagrams), AI extended the use of computers to problems more complex and less structured, including the highest form of reasoning, reserved until then for human judgement (Simon, 1996). The development of AI also contributed to the emergence of an epistemological reflection on the legitimacy of its disciplinary roots. Simon, along with others, initiated what might be interpreted today as a constructivist epistemology of complexity (Le Moigne, 2001a).

Systems Sciences

After prolific use during the 18th century and intense criticism during the 19th, the notion of 'system' emerged again with the development of cybernetics. In 1945, Von Bertalanffy developed the idea that organised wholes of any kind should be describable, and to a certain extent explainable, by means of the same categories, and ultimately by the same formal apparatus. His 'general systems theory' (Von Bertalanffy, 1951) and the initial contribution of Boulding, Gerard & Rapoport triggered a movement during the 1950s that tried to identify invariant structures and mechanisms across different kinds of organised wholes (Schwaninger, 2005). During the next decades, this trend helped to bring about the elaboration and the implementation of a set of methodologies that aimed to represent phenomena of organised complexity by allowing both for the anticipation of their behaviours and the consequences of intentional intervention. Since the 1970s, the influence of systems theories followed two different paths, epistemologically antagonistic. The first, as it appears, for example, in the work of Forrester (1961) on 'system dynamics' and the work of Churchman (1968) on 'system approach', allowed for the emergence of techniques reducing the complexity of a system to the study of its components and their relationships understood as objective phenomena. Influenced by the contributions of Piaget, Bateson, Simon, Von Foerster and Morin, a second tradition favoured a definition of complex systems by acknowledging the constructivist nature of their modelling. Such a perspective contributed to an understanding of complexity that recognised the importance of the relationship binding the observer to a phenomenon (Le Moigne, 2001a).

Self-Organisation

The concept of self-organisation—used in the 1930s by Von Bertalanffy to characterise the central feature of organismic development and by Gestalt psychologists to describe the way humans process experience (Fox Keller, 2004)—benefitted from a lot of attention during the early 1950s. Its definition was energised by the contribution of several theories: the work of Von Neumann (1966) on 'self-reproducing automata' (developing the idea of an artificial machine capable of reproducing itself); the research of Ashby (1956) on 'cybernetics variety' (describing the correspondences between the behaviours of a system and the configuration of relations among its components); the invention by Rosenblatt (1958) of the 'Perceptron' (a device whose neuron-like connections should allow it to perceive, recognise and identify its surroundings without human training or control); and finally, the contributions of Von Foerster (1960, 1996) on 'non-trivial systems' (describing autonomous organisations as systems whose inputs are not totally independent of the feedback produced by their outputs). These contributions helped shift the orientation of cybernetics (identified later as 'second-order cybernetics') toward conceiving complex organisations as autonomous systems whose evolution is a function of both their environment and the relationships among their own components. Enriched by the work of Atlan (1972), this renewed conception of self-organisation helped to redefine complex organised phenomena as emergences, produced not only from their constituting order, but also from the disorder (noise or fluctuation) characterising the relations among their own components.

The Study of Non-Linear Dynamics: Dissipative structures, catastrophe, chaos and fractal theories

During the same period, progress in the understanding of self-organised phenomena had major consequences for the study of non-linear dynamics. In 1969, Prigogine's discovery of 'dissipative structures' marked a shift in thermodynamics that sparked a reconsideration of the idea of entropy. His team demonstrated the possibility that an irreversible process (dissipation of energy) far from a steady-state is able to play a constructive role and become a source of order. His description of dissipative structures brought new insights into the way molecular disorder is able to regress (steady zone) and the ways in which circumstantial fluctuations can amplify themselves (bifurcation) to bring the system into a new state characterised by a specific stability (Prigogine & Stengers, 1984). Allowing for a categorisation of the dynamics of non-linear systems depending on their behaviour, the 'catastrophe theory' elaborated by Thom (1975) contributed to an understanding of the relationships between stationary states, changes and ruptures affecting the transformation of regular physical phenomena in discontinuous and singular manifestations. Emerging in the early 1970s, 'chaos theory' provided a framework to describe system behaviour depending so sensitively on its precise initial conditions that it is unpredictable and cannot be distinguished from a random process, even though it is deterministic in a mathematical sense (Gleick, 1987). Finally, the concept of 'fractality', introduced in 1975 by Mandelbrot (1983), referred to the geometrical characteristics of natural phenomena that are statistically self-similar (a fractal is an infinitely complex recursively constructed shape: a magnification of a part of one sample can be matched closely with some other member of the ensemble), allowing geometrical order to be perceived in apparent disorder. Through these developments, the study of non-linear dynamics drastically renewed the vocabulary associated with complexity and the resources available to describe it. Contributing to the development of mathematical and conceptual resources that enabled a revisiting of the relationships between fluctuation and stability, non-linearity and linearity, randomness and non-randomness, the study of non-linear dynamics also provided a framework that helped to describe the complexity of any morphogenesis (Dahan Dalmedico, 2004; Morin, 1977/1980).

Evolutionary Biology

During the 1960s, the progress of technology and developments associated with cybernetics and with self-organisation challenged traditional approaches to biology. On one hand, with the discovery of DNA, new theories were developed to explain the emergence of life as the predictable, even if improbable, consequence of physical and chemical laws characterised by the presence of disorder (Monod, 1972). Evolution was revisited through new statistical models (Dawkins, 1989), illuminating in particular its chaotic nature (Gould & Eldredge, 1977). On the other hand, new theories built new bridges between the development of life and the emergence of cognition, among them the contributions of Bateson (1973) and the work of Maturana and Varela (1992), grounded in Maturana's initial research on *autopoiesis*. (An autopoietic system is organised as a unified whole, the parts of which continue, through multiple interactions and transformations, to realise and produce relations that have themselves produced the network of processes in the first place. Autopoiesis affirms living systems as without essence [see Semetsky, 2008, in this volume].) Providing new representations of 'adaptation', 'evolution', 'self', 'autonomy' and 'emergence', this research positioned the study of the evolution of life at the centre of the ensuing developments informing the understanding of complex phenomena.

Third Generation

During the 1980s, complexity research followed two different paths. The first, more visible in the English-speaking field through the study of 'complex adaptive systems', is perhaps best understood to lie at the border between recent developments in non-linear dynamics, evolutionary biology, and artificial sciences. The second, more prevalent in Latin countries, is characterised by a reflexive dimension that aims to explore new ways of representing multiple complexities and that promotes an epistemology driven by the will of scientists to determine, conceive and construct the rules of their own action, including ethical ones.

Complex Adaptive Systems

In the early 1980s the expression 'complex adaptive systems' (CAS) emerged with the creation of the Santa Fe Institute in New Mexico:

> [E]mphasising multidisciplinary collaboration in pursuit of understanding the common themes that arise in natural, artificial, and social systems [t]his unique scientific enterprise attempts to uncover the mechanisms that underlie the deep simplicity present in our complex world. (Santa Fe Institute, 2005)

Among the theories informing this trend were: the work of Holland (1992) on a 'genetic algorithm' (an attempt to model the phenomena of variation, combination and selection underlying most processes of evolution and adaptation); the research of Kaufmann (1993) on 'Boolean networks' (grounded in the study of properties related to networks of genes or chemical reactions in an evolutionary perspective informed by self-organisation); the research of Bak (Bak & Chen, 1991) on 'self-organized criticality' (aiming to describe the evolution of physical or living phenomena toward a 'critical edge' located between stability and chaos); and the work of Wolfram (2001) on 'cellular automata' (using mathematical models and computer simulations to describe evolution of chaotic phenomena). As illustrated by the work initiated by Langton (1989) on 'artificial life' (software and hardware created to reproduce behaviours similar to those characterising natural living systems), the study of CAS reinforced an ascendant logic of research: aiming to model and simulate behaviours presenting analogies with organic, ecological or socially complex phenomena (Helmreich, 2004; Heylighen, 1997), it reinforced an understanding of complexity requiring researchers to create and organise the rules of its conception, instead of trying to infer them from empirical observation.

Intelligence de la Complexité

In spite of a rich proliferation of theories, the development of epistemological reflections around the concept of complexity is relatively recent. Between 1945 and 1975, the status and epistemological legitimacy of sciences constituted within the paradigm of organised complexity was rarely investigated and the term 'complexity' seldom used (Le Moigne, 1996). Books published in the late 1970s that are now considered classics, contributed to the new wave of epistemological and conceptual research developed at that time (see, for example, University of the United Nations, 1986). In France, the work of Morin is located at the core of these contributions.[1]

In the 1960s Morin's research on the anthropology of knowledge (Morin, 1973, 1977/1980, 1980, 1986, 1991) developed an approach that involved a reorganisation of the various conceptions of complexity from the 1940s. Morin framed significant epistemological critics by going beyond the usual dualisms (positivist and realist versus constructivist; Cartesian versus non-Cartesian, etc.), and used these contributions to question the limitations of contemporary processes of knowledge production. Located at the intersection of philosophy, physics, biology and human sciences, his reflection created an epistemic loop that associated the emergence of 'organised' knowledge (sciences) with the creation of 'organising' knowledge (Le Moigne, 1996). His paradigm of 'self-eco-re-organization' (*auto-éco-ré-organisation*) criticised the epistemological and institutional compartmentalisation of the contemporary sciences and philosophies. Advocating the emergence of a kind of science that endorsed an 'en-cyclo-paedic' process (which builds in cycles rather than in a linear accumulation of knowledge), his approach related fragmented scientific fields of study with each other. Grounded in an open network of concepts and principles of thought, Morin advocated a conception of complexity that dispensed with the antagonist, contradictory and complementary tensions which shape its own understanding. Aware of its own biological, physical and anthropological foundation, a complex thought involves the integration of both the complexity of our identity as human beings (Morin, 2001) and the complexity of ethical issues generated by a conception of science understood through its own uncertainty (Morin, 1973, 2004). Reinterpreting both the epistemological and the political nature of these theories, the work of Morin contributed to the legitimacy of several trends of research sharing the same ethical commitment with regard to the construction of new models of knowledge production (see for example, the European programme, MCX '*Modélisation de la complexité*', 2005).

Keeping Complexity Complex

In one sense, the genealogy sketched in this paper may lead one to believe that the development of theories today associated with complexity has followed a linear path, representative of the order which constitutes them. But in another, the heterogeneity of meaning and the multiplicity of definitions, trends and fields of study in which they have taken their roots illuminate the constitutive disorder which shaped their evolution. To identify the contributions associated with this notion requires that we position ourselves with regard to such ambiguity. To do so, it seems relevant to consider from a socio-cultural point of view the epistemological variations underlying complexity theories and some of the ambiguities they convey.

Epistemological Variations

From an epistemological point of view, the ambiguity associated with the development of complexity theories is linked to the fact that historically they have evolved in a space of representations, constituted simultaneously by antagonistic, contradictory and complementary positions. Complexity may be considered an ontological dimension of the object of study, some understandings of which suggest reduction to specific characteristics and representation through a set of all-embracing algebraic expressions. Its states and behaviours can in these views be described and calculated with certainty, following a computing process. In these perspectives, the evolution of this kind of system can be predicted, more or less accurately, through programmable algorithms. The possibilities are considered as foreseeable. The behaviours observed are considered as being explainable, and then predictable, by a theory, a rule, or an invariant structure. If the computational capacity of the observer practically limits such a prediction, the development of more sophisticated computing devices allows its advocates to believe in the great potential of this position (Le Moigne, 1996). Historically, such an approach is at the core of the development of an understanding of 'organised complexity' as predicted by Weaver. Today, it underlies various trends recognised by many as 'reductionist', whose limitations brought them to be associated with the notions of 'complication' or 'hyper-complication' (Ardoino, 2000; Le Moigne, 1996, 2001a; Lissack, 2001; Morin, 1977/1980, 2007).

However, since the 1970s, a 'softer' position has emerged. Considering concepts associated with complexity as powerful metaphors to describe or understand socio-cultural phenomena, this position contributed to a new vocabulary to interpret reality. Recognising similarities and differences between various levels of organisations (physical, biological, social, etc.), this position contributed to the development of analogies between them. Because of the relative paucity of reflection on the validity of these comparisons, their epistemological legitimacy remains largely unchallenged, but some authors have identified them as 'pseudo-scientific' (Le Moigne, 2001a; Phelan, 2001).

In parallel with these perspectives, a third position may be identified. In contrast with 'hyper-complication', it suggests that complexity is associated with situations where the observer is aware of the impossibility of defining the list of potential states of a system, or the list of contributing factors. It invites an approach to complexity that is no longer a matter of explanation or prediction. Conceived as an interpretation, complexity is a characteristic attributed by the observer to a phenomenon. It is, above all, a key element of a representation built by the researcher, and not necessarily an aspect of the ontology of the object of study. It is thus in some senses a constructivist understanding of complexity (Le Moigne, 1996, 2001a, 2001b, 2003).

These positions are prototypical, and as such invite consideration of at least two issues that influence the positioning of complexity as a point of view. The first refers to the level of closure attributed to the definition of complexity. Associated with a set of identified components, complexity is reduced to (hyper-)complication; extended to an open-ended list, its definition loses its specificity. In between, it involves a process of negotiation of its meanings, thus adding a layer of ambiguity. A second issue concerns the type of representation privileged to describe it. The contemporary success of complexity is embedded in both the power of the metaphors and the efficiency of the algorithms associated with it. To be represented and discussed, complexity involves translations between symbolic, formal, and informal languages. These interpretations necessarily add a layer of uncertainty.

Socio-Cultural Ambivalences

Besides or because of their epistemological ambiguity, theories related to complexity are also ambivalent from a socio-cultural point of view. On one hand, complexity theories have substantial emancipatory potential. Concepts like 'control', 'autonomy', 'organisation' or 'self' may enrich our representations of alienation and emancipation as complex processes. They might encourage reconsideration of the meaning of social and philosophical critique (Alhadeff, 2003, 2004; Alhadeff-Jones, 2007b; Geyer, 1980; Morin, 1977/1980, 1980, 1986). The development of complexity theories is also associated with the emergence of new formal logics (Morin, 1991) and new ways of knowing (Fabbri & Munari, 1984/1993). Complexity theories have contributed to the promotion of non-dualistic, non-hierarchical and non-linear representations, reframing ways of understanding contemporary issues. Trends initiated around this body of research also invite reconsideration of a plurality of (old and new) disciplines by challenging their epistemological legitimacy (Le Moigne, 2001b; Morin, 1999). From 'multireferentiality' (Ardoino, 1993) to 'transdisciplinarity' (Nicolescu, 1996, 2005; Paul & Pineau, 2005), complexity has contributed to a critique of traditional modes of organising knowledge. Transversal approaches have emerged, renegotiating ways of conjugating heterogeneous forms of knowledge and of crossing institutional compartmentalisation, without falling into the trap of eclecticism or relativism.

At the same time, complexity theories also carry the potential of perpetuating new forms of intellectual and social alienation (Lafontaine, 2004). Through the importance they give to technological development and the concepts and metaphors they convey, these theories perpetuate a set of values, a vocabulary, even an ideology, which may contribute to perpetuating specific forms of domination (Lafontaine, 2004; Morin, 1977/1980, 1980, 1986, 1991; Musso, 2003; Boltanski & Chiapello, 1999)[2].

Complexity theories can be accused of the reduction of phenomena to a set of mathematical variables and abstract models, and also of the production of pseudo-scientific analogies grounding new theories and practices in illegitimate frames of interpretation. Furthermore, as a result of their heavy anchorage in physics, biology, engineering, management, etc., some of the concepts framing the contemporary understanding of complexity in connection with, say, the study of education, represent a risk of reducing education's associated concepts and issues to a narrow set of perspectives.[3]

Towards a New Form of Critique?

Complexity theories do not of course necessarily bring about an improvement in research into education, especially from an ethical and socially aware point of view. Because science is also the result of complex processes (Alhadeff-Jones, 2007a, 2007b, in press; Morin, 1986, 1991), the benefits of any of these contributions cannot be taken for granted. To go beyond the fashion of a 'new' set of concepts, one has first to consider how these theories might enable us to rethink educational theories. Critical consideration of education, grounded in contemporary theories related to complexity, as well as in a critical appraisal of their epistemological and ethical legitimacy, has to be considered by following the loops and dynamics they constitute (Alhadeff, 2005; Alhadeff-Jones, 2007b). One of the new challenges for educational theorists is probably to be able to work on the following at the same time: the construction of an original form of critique able to deal with phenomena perceived as complex and the elaboration of a critique able to dialogue with a body of theories which do not fit traditional epistemic frames of reference. Complexity is a 'word-problem' and not a 'word-solution' (Morin, 1990). In the study of education, it should invite us to consider the problems raised by its own irreducibility to existing frames of thought at least as much as the solutions it appears to offer. Complexity should invite us to challenge our ways of interpreting science and philosophy, as well as our ways of interpreting the world. A specific kind of learning may thus be reinforced in these challenges: the ability of educational researchers and practitioners to build systems of representation that allow them to confront more systematically their own transformation, as they conceptualise the transformation they are studying.

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Notes

1. Although the research of Morin has been translated into many languages, references to his work are relatively few in English-speaking countries. Among the rare texts related to complexity that are easily available in English are: Morin, E. (2007) Restricted Complexity, General Complexity, in: C. Gershenson, D. Aerts & B. Edmonds (eds) *Worldviews, Science and Us, Philosophy and Complexity* (London, World Scientific) pp. 5–29; Morin, E. & Kern, A. B. (1999) *Homeland Earth* (Creskill, NJ, Humpton Press); Morin, E. (1992) *Method: Towards a study of humankind. Volume 1: The nature of nature* (New York, Peter Lang); Morin, E. (1992) From the Concept of System to the Paradigm of Complexity, *Journal of Social and Evolutionary Systems*, 15:4, pp. 371–385; Kofman, M. (1996) *Edgar Morin: From big brother to fraternity* (London, Pluto Press).
2. See, for example, the historical work of Musso (2003) grounding a critique of the concept of 'network'; see also the sociological work of Boltanski and Chiapello (1999) illustrating and theorising how, since the late 1970s, the introduction in management of concepts associated with complexity affected and reinforced the discourse legitimising the mutation of capitalism, redefining ways to negotiate power dynamics and social critiques.
3. It seems relevant to consider the fact that several key theories informing the idea of complexity find their roots in military research during the Second World War and the Cold War (Fox Keller, 2004; Lafontaine, 2004), and have contributed to major business-oriented development as well. In the same way, contemporary developments like 'artificial life' appear to be grounded in Western masculine world-views that perpetuate a specific set of representations (Helmreich, 2004).

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