COMPARATIVE THEORETICAL STUDY BETWEEN CHAOS THEORY AND INNOVATION PROCESS

ESTUDO TEÓRICO COMPARATIVO ENTRE TEORIA DO CAOS E PROCESSO DE INOVAÇÃO

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Abstract
This article aims to gather concepts and ideas and provide reflections to offer the reader a basis that makes possible a question about the degree of similarity between chaos theory and innovation. Unlike the name, chaos theory is linked to discovering simple patterns and laws that govern several complex phenomena. The complex is also innovation; therefore, this article makes an analogy of the innovation process from its conception to its implementation in the market with three principles of chaos theory: system, nonlinearity, and complexity. The innovative organization is characterized by constant innovation and complexity in nature. Uncertainty is an essential feature of innovation, which means an inability to predict the prospecting processor's outcome to set the best way to achieve a goal. Unpredictability is one of the characteristics of chaotic systems in which any minimal initial change in their conditions causes drastic changes in their course. Based on these premises, analogies were made to serve as a basis for further studies.
Keywords
Chaos theory, innovation, uncertainty environment

Resumo
Este artigo tem como objetivo reunir conceitos, ideias e proporcionar reflexões para oferecer ao leitor um embasamento que torne possível um questionamento a respeito do grau de semelhança entre a teoria do caos e o processo de inovação. Diferentemente do que o nome parece ser a teoria do caos está ligada a descoberta de padrões e leis simples que governam uma série de fenômenos complexos. Complexa também é a inovação, portanto, este artigo faz uma analogia do processo de inovação desde a sua concepção até a sua implementação no mercado com três princípios da teoria do caos: sistema, não linearidade e complexidade. A organização inovadora é caracterizada por uma constante inovação e de natureza complexa. A incerteza é uma característica essencial da inovação, o que significa uma incapacidade de prever o resultado do processo de prospecção ou de definir o melhor meio para atingir uma meta. A imprevisibilidade é uma das características dos sistemas caóticos em que qualquer mínima mudança inicial nas suas condições, provoca drásticas mudanças em seu rumo. Com base nestas premissas foram feitas analogias para servir como base para novos estudos.
Palavras chaves
Teoria do caos, inovação, ambiente de incerteza

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Introduction

Companies seek to achieve their goals by competing in a market involving products, competition, efficiency, profit, quality, learning capacity, and many others. Therefore, they develop innovative products, processes, and services. However, Dougherty (1999) states that organizations face different problems when they innovate. Uncertainty is one of them because it is an essential characteristic of innovation, which means an inability to predict the prospecting processor's outcome to pretend the best way to achieve a goal. In a way, it implies limitations for its planning (ROSEMBERG, 1994).

For Kiel (1989), we live in a period of rupture, from the disruption of the Taylorist-Fordist model to flexible specialization models' appearance, based on open systems. A world of accelerated change, disorder, instability, and not balance. Unavoidable and chaotic environments form the idea of complexity and environmental Chaos. In this scenario, the Chaos Theory finds a fertile field based on its studies on the tripod: systems, nonlinearity, and complexity (WOOD JR., 1995; RUELLE, 1991).

The innovation process involves steps that can be adapted according to the peculiarities of each company. The innovative organization is characterized by constant innovation. Complex nature uncertainty is an essential feature of innovation, which means an inability to predict the prospecting process's outcome or pretend the best way to achieve a goal. Unpredictability is one of the characteristics of chaotic systems in which any minimal initial change in their conditions causes drastic changes in their course. Based on these premises, we made the studies of analogies that we describe in this article. From this study, three points of correlation between innovation and Chaos theory were related: system, nonlinearity, and complexity.

Theoretical Framework

Innovation

Companies engage in innovation for several reasons. The objectives may involve products, markets, efficiency, quality, learning capacity. Implement changes, improve the quality of its production, revitalize mature businesses, enter new markets, react to the advancement of competition, try new technologies, and leverage investments in new technologies (DOUGHERTY, 1999). Therefore, they need to develop new products and services that are viable. Identifying the reasons that lead companies to innovate and their importance helps understand the forces driving innovation activities, such as competition and opportunities to enter new markets.

For Dougherty (1999), several problems are faced by companies to innovate, such as: adopting new technologies; away from customers who are accustomed; change its strategic paradigm; break with prevalent decision-making models; adjust your product architecture; use marketing tools appropriately; learn based on experience. Rosenberg (1994) states that uncertainty is an essential feature of innovation, which means an inability to predict the prospecting processor's outcome to pretend the best way to achieve a goal, which implies limitations for its planning.

The innovative organization is characterized by a constant complex innovation involving complex technologies or systems under conditions of dynamic change. They are dependent on a multidisciplinary team where specialists work together, with highly organic structures, little formalization, specialized positions, and the tendency to group specialists into functional units, but are matrix allocated in small project teams to carry out the work. They have high confidence in teams and task forces, strong integration between managers who aim to harmonize adjustments and coordinate efforts between teams, good decentralization of operations, multiple management roles, including functional managers, projects, integration (MINTZBERG, 2001).

As innovation requires escaping established standards and remaining flexible, bureaucratic structures are less targeted, mainly avoiding rigid labor divisions, unit differentiation, highly formalized behaviors, and formal planning and control systems. The information and decision processes flow flexibly and informally, including going over the chain of command if necessary since coordination needs to be exercised by those who know, the specialists themselves, and not by those who hold only authority. As a stimulus to innovation, the organization uses a whole set of liaison devices: inter-relationship of personnel, integration of managers, teams, and taskforces (MINTZBERG, 2001).

According to Rothwell (1992), we can define the evolution of innovation in five generations: the first a linear model "pushed" by technology where the process begins in research activity, it continues in development, passes through production and then reaches the market; the second is a linear model "pulled" by the market, demand determines both the direction and degree of inventive activity; the third is a coupled model, recognizing the interaction between different elements and feedback between them, it seeks to integrate these two approaches by considering that both the growing knowledge base of science and technology, and the structure of market demands, play central roles in innovation in an imperative way (MOWERY; ROSEMBERG, 1979); the fourth is a parallel model, integrates the company's internal innovation with innovation in partnership with customers and suppliers, placing emphasis on alliance links, emphasizes the integration and parallelism between innovation activities, so that R&D, production and marketing are simultaneously engaged in the innovation process as an integrated development team; and the fifth and last generation is systemic integration, with vital networking, flexible and personalized responses, continuous innovation, is an approach that leads to the integration and parallelism of activities one step further, with application of information technologies to streamline the product development process.

The innovation process has evolved from a strictly sequential vision to a more interactive approach. The sequential models reflected a simplified view of the innovation, where products were pushed to market. In the interactive approach, innovation is a learning process involving technological possibility, competence, and the market's need. R&D, production, and marketing are simultaneously engaged in the innovation process as an integrated development team. Customers and suppliers also play a crucial cooperative role, and even competitors are considered partners in strategic alliances and *joint ventures* (ROTHWELL, 1992, 1994).

The innovation process involves steps that can be adapted according to the peculiarities of each company, such as: prospecting the internal and external environment where it will identify and process relevant data on threats is opportunities related to change; decision-making based on a strategic vision; obtaining resources to enable the creation of something new through research and development, which can be acquired from the externally through technology transfer and implementation of the project through the development of technology and internal or external market (TIDD; BESSANT; PAVITT, 1997).

Product innovation is also defined through the following steps: definition, development, operationalization, manufacturing, launch, and continued management of a new product or service (COOPER, 1983). Innovation is cross-functional because it involves all functions and aspects of administration. By involving perceptions and social construction, innovation is also ambiguous (DAFT; WEICK, 1984). The design and development of a new product go through complex situations requiring innovators to solve problems, overcome unforeseen events, overcome barriers, unify processes with different functions and interconnect resources from different locations. Innovators must solve several issues, and at the same time, they must focus on problems that affect various functions and solve them considering the limitations of other functions (YANG, DOUGHERTY, 1993).

Organizing to solve problems is a multifunctional process. Several functions will be performed at the same time. For Clark and Fujimoto (1991), innovators' coordination of such interdependent activities must consider limitations in other functions, anticipate needs, and use two-way communication to process incomplete information. Responses to task needs make relationships between team members adapt to each other (LEONARD-BARTON, 1988). Decisions should not be postponed and must be made quickly. Otherwise, more minor problems will grow like a snowball, turning into huge problems.

Working together by different functional areas in troubleshooting results in time gain in the project. However, there must be discussions between the teams; communication must be intense, bidirectional, early, and intensive. Not only means the existence of ethics, unity, creativity, and the absence of conflicts; the essence for integration is real-time coordination between the different areas involved. The communication model adopted by the company is essential. The result of the work of a given area will be the entry into the activity of another. The degree to which the functions relate determines the effectiveness of the integration (CLARK; WHEELWRIGHT, 1995).

Organizations face difficulties in multiple project cases, and a new product requires new supplier relationships and new sales procedures. These operations can conflict with the existing procedures created for the old products. These tensions can be managed through a collaborative and communications team. The problems are not restricted to the team control of an innovation project because for an organization to be innovative, innovations must be foreseen throughout its budget process (DOUGHERTY, 1999).

Dougherty (1999) says that changes in markets, technologies, or competition can quickly turn a good idea into a bad one. The planning of projects for the development of new products and their alignment with the companies' business strategy and

planning can be considered determining factors for the success of the new products developed and the company in the market in which it operates. In a product development process (PDP), a set of activities from various areas are involved. These activities are essential for product and process development. The integrated approach with focus is essential to getting project choices based on process capabilities and process capabilities to meet project requirements (CLARK; WHEELWRIGHT, 1995).

Clark and Wheelwright (1995) affirm that often, there may be failures in communication between areas, which can generate project failures that can delay a launch, harming the potential advantages that the project provided. There must be a dysfunctional integration between the activities and their time spent performing between the different functions. Cross-functional integration is much more than merely coordinating activities; the actions of various functions must support and reinforce each other. Integrating two areas or functions inter-functional means that, between them, it understands and exploits the inherent potential and capacity of the product or process (CLARK; WHEELWRIGHT, 1995).

Chaos Theory

We live in a rupture period, from the disruption of the Taylorist-Fordist model to flexible specialization models' appearance, based on open systems. A world of accelerated change, disorder, instability, and non-balance (KIEL, 1989). Unavoidable and chaotic environments form the idea of complexity and environmental Chaos. In this scenario, the Chaos Theory finds a fertile field (WOOD JR., 1995).

In the 1930s, organizing had the sense of segmenting, planning, ordering, and controlling. In the 1960s and 1970s, organizations were the "driving spring" of modernity in a complex and poorly understood environment (WOOD JR., 1995). Heisenberg, in 1927 had made the presentation of the principle of uncertainty related to quantum mechanics. However, after the sixties, the search for the deterministic order of nature became the object of study (HEIZENBERG, 1949). Scientific disciplines are broken by the boundaries that separate them from chaos theory, which had its origin from hard *science* (GLEICK, 1999). Because it is a science of the global nature of systems, it brought together thinkers separated in their fields. Organizations and their administrators go through transformations and instabilities that dominate this new scenario. Metaphors present ideas and images related to the natural sciences to understand organizational phenomena (WOOD JR. 1995).

In the 1960s, Chaos Theory studies topics such as evolutionism, self-organization, and complexity. As opposed to the idea of a disarray scenario, chaos theory is linked to the discovery of simple patterns and laws that govern several complex phenomena. It is characteristic of chaotic systems the "sensitive dependence of the initial conditions" (GLEICK, 1999: 20), and therefore, it is possible to affirm that there is no predictability, but rather the unpredictability that happens to the part of any minimal change in one of its initial conditions can cause profound variations affecting in the final results its trajectory or behavior (WOOD JR., 1995). The famous "butterfly effect" where Edward Lorenz, with his weather models, discovered that a variety of initial conditions made nonlinear interactive systems extremely sensitive. Lorenz summed up in his phrase, " A butterfly flapping wings in Brazil can cause a tornado in Texas¨ (Wood, 1995).

Because it is a scientific theory still developing complex linear systems and not well-defined limits, chaos theory is based on its studies on the tripod: systems, nonlinearity, and complexity (RUELLE, 1991).

A system is a set of interrelating units, where each part depends on the other (WOOD JR.,1995). The famous classic example of the stone pile (RUELLE, 1991) shows the mutual relationship and interdependence when removing a stone from the base, causing a collapse of the pile and the search for a new reorganization and a new state of equilibrium. As the system is dynamic, the stone pile will reorganize to balance each new change in the base.

Nonlinearity is related to the mathematical structure used to represent the behavior of the natural system. Chaotic systems have irregularities and extreme sensitivity to initial conditions (BORMAN, 1991). They are deterministic, although they appear completely random and are often described by simple mathematical equations. Since the initial conditions are not known, it is not known what will happen. The change in one variable should produce non-proportional changes in another variable, meaning the absence of constant proportionality.

The term complexity is related to structuring a model to predict an entire system's behavior. As in the chaos theory, some behaviors precede certain generated systems, and it can be affirmed that there is no predictability and controllability (WOOD JR., 1995). It cannot be said with certainty that an object's time always on the same path will be the same because its proportionality between distance and speed can be changed by its variable displacement speed caused by unpredicted factors.

In the theory of Chaos, nothing is simple, taking as an example the stone pile collapsing to predict the behavior of the pile. It is crucial to obtain details about each stone. Shape, weights, measures, places are inserted in a pile, the interdependence of each stone, and the influence on the others due to frictions. Still in possession of all the information cited, if a simple grain of stone is discarded, however small, the prediction's result will be very different from the natural system. Also, the significant dependence on initial conditions is one of the characteristics of complex systems. Chaos is a seemingly stochastic behavior that occurs in a deterministic system (Stewart, 1988), where many time series of data, initially considered random behavior, can present deterministic patterns. One of the fundamental aspects of Chaos is hypersensitivity to initial conditions; it is a result of prediction, for a system, is very sensitive to its initial state. The hypersensitive dependence of the initial conditions occurs when in the initial state of time zero, a small change produces a change that grows exponentially over time. Therefore, a small cause has a significant effect. (RUELLE, 1993).

As opposed to lack of order, chaos theory is linked to simple patterns and laws generating complex phenomena. This is not to say that there is a pattern with the possibility of predicting behavior. Unpredictability is one of the characteristics of chaotic systems in which any minimal initial change in their conditions causes drastic changes in their course (WOOD JR.,1995). Theories such as the Paradigm of Complexity and Systematic Theory and chaos theory, providing a new vision to complex systems forming organizational structures (WOOD JR., 1995).

Chaos Theory applied to the context of business administration is called complexity. The companies are highly complex systems where control is achieved balancing at the edge of Chaos, where neither many restrictions nor total disorder is desirable (BEINHOCKER, 2000).

In the view of complexity, Chaos refers to dynamic systems' behavior resulting from dependence on the initial conditions. Compared to what could be concluded intuitively, chaotic behavior is not related to external factors' influences. Chaotic behavior originates internally in the system itself. Therefore, in the approach to complexity, Chaos represents a different concept from that commonly associated with this word. (GIOVANNINI, 2002: 26).

Organizations are sets of people who do not act the same way without considering the situation in question. They are complex systems but self-organizing. People act to do right, knowing how and when to change things (STACEY, 1993). In doing so, they find order in Chaos (EISENHARDT; BROWN, 1998). Complexity helps understand how an organization must change to handle complex and unpredictable environments, connecting change, Chaos, and organization, establishing new reference structures in strategic and organizational management.

Methodology

This theoretical study is considered exploratory through bibliographic data collections to make a relationship between chaos theory and the innovation process in organizations, seeking points that correlate between the two topics and can serve as a basis for further studies. According to Demo (1994; 2000), theoretical research provides reconstructing a theory, concepts, ideas, ideologies, polemics, providing improved theoretical foundations.

Analysis of the relationship between Chaos Theory and Innovation

It was emphasized that a chaotic system is a deterministic system; a deterministic differential equation determines its behavior. Thus, the evolution of a chaotic system does not present absolute disorder, but rather a particular order that, due to its hypersensitivity to initial conditions and its nonlinear and complex structure, is practically unpredictable in the long term, regardless of obtaining an equation with highly significant parameters that fit the data. It was seen that the chaos theory is based on its studies the systems, nonlinearity, and complexity (RUELLE; 1991).

The innovation process involves stages of prospecting, decision making, obtaining resources, and implementation. When it comes to product innovation, it is also defined through the following steps: definition, development, operationalization, manufacturing, launch, and continuous management of a new product or service (COOPER, 1983). In addition to perceptions and social construction, innovation involves all functions and aspects of administration. That is why an innovative organization goes through complex processes under dynamic change conditions (MINTZBERG, 2001).

The theory of chaos system is a set of units that interrelate, where each part depends on the other (WOOD JR.,1995). In innovation, working together by different functional areas in problem-solving is necessary for discussions between teams. These multidisciplinary teams are interrelated, and the essence of integration is real-time coordination between the different areas involved (CLARK; WHEELWRIGHT, 1995). The result of the work of a given area will be the entry into the activity of another. The degree to which the functions relate determines the effectiveness of the integration (CLARK; WHEELWRIGHT, 1995). Compared to the classic example of the stone pile (RUELLE, 1991), it shows interrelationship and interdependence when removing a stone from the pile's base. It is reorganized in search of a new state of equilibrium. Like innovation, when the fault between areas by communication or wrong definitions occurs, they must be corrected for a new alignment between areas. A change or displacement of the area causes changes in the project that can delay a launch, harming the potential advantages that the project provided (CLARK; WHEELWRIGHT, 1995).

Nonlinearity in chaos theory is related to the mathematical structure used to represent the real system's behavior. Chaotic systems have irregularities and extreme sensitivity to initial conditions (BORMAN, 1991). Since the initial conditions are not known, it is not known what will happen. The change in one variable should produce non-proportional changes in another variable, meaning the absence of constant proportionality. In innovation, nonlinearity is related to decision-making in the prospecting or definition period. As uncertainty is an essential feature of innovation, which means an inability to predict the outcome of the prospecting processor to enter the best means to achieve a goal (ROSEMBERG, 1994), depending on the various decision-making options in the initial prospecting process, the results will be distinct and unpredictable.

The term complexity is related to structuring a model to predict a real system's behavior. Chaos Theory, being deterministic due to the behaviors of certain systems generated by simple equations, overthrows the myth of traditional science of predictability and controllability (WOOD JR., 1995). In the process of innovation related to complexity is seen two situations: the first is related to the period of development until its implementation, at this stage, all the planned schedules may suffer delays or changes due to uncontrollable factors, such as a machine breakage or even remembering that the organizations are sets of people, who do not act in the same way and are not predictable, a strike can occur; the second situation is related to the launch of the product to the market, this may not correspond to the expected objectives in terms of expected return time due to various factors that influence the consumer. The prospecting period or definition was not mentioned because this period was related to the initial process, related to nonlinearity.

Final considerations

This work proposed a relationship between chaos theory and innovation, showing the correlation between the two studies. We sought to understand innovation and its

complexity through chaos theory. As a result, innovation has points in common with chaos theory in analyzing three aspects: system, nonlinearity, and complexity related to the innovation process.

Due to the importance of innovation in organizations, the administrator needs to understand its complexity and reduce uncertainties to minimize risks. In this work, it was found that it is possible to make correlations with the chaos theory to understand the processes of innovation better and adjust them. This makes it a little more predictable through new studies to obtain a competitive advantage. Although this was a comparative bibliographic study between the two theories, this study found a basis for deepening these relationships from new research in the organizational environment.

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