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Chaos/Complexity Theory and Education

Mansour Fahim
Associate Professor, Allameh Tabataba'i University

Fattaneh Abbasi Talabari
Ph.D student, Allameh Tabataba'i University

Abstract

Sciences exist to demonstrate the fundamental order underlying nature. Chaos/complexity theory is a novel and amazing field of scientific inquiry. Notions of our everyday experiences are somehow in connection to the laws of nature through chaos/complexity theory's concerns with the relationships between simplicity and complexity, between orderliness and randomness (Retrieved from http://www.inclusional-research.org/comparisons4.php). It is interested in how disorder leads to order, of how complexity emerges in nature. There appears to be many striking and eye-catching similarities between the new science of chaos/complexity and education. An understanding of chaos/complexity theory seems almost crucial to our general understanding of education and teachers' and students' needs within educational systems. Chaos/complexity theory raises some very significant issues in an educational context, including responsibility, morality and planning; the significance of non-linear learning organizations; setting conditions for change by emergence and self-organization; the role of feedback in learning; changing external and internal environments(Morrison, 2006); it emphasizes on the fact that schools and learners as open, complex adaptive systems; cooperation and competition; pedagogy; and the significance of context (Larsen Freeman, 1997).This paper tries to provide an overview of this science and how it can inform education.

Key Words: Chaos, Complexity, Fractal

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E-mail:dr.manfahim@yahoo.com
E-mail:fattaneh2632@yahoo.com

Introduction

Chaos/complexity theory was developed to help us understand highly complex systems. It helps us recognize that on the basis of any apparently chaotic behavior of a complex system lie certain patterns that can make one be aware of the impacts of this theory on the behavior of the system. This paper begins with a summary of some of the key features of chaos/complexity theory and then explores the ways this theory informs education.

Background

The universe is a chaotic place, full of uncertainty. It can be extremely difficult to predict exactly what is going to happen in the universe at any given time, be it the present or the far future. The word chaos has a slightly different connotation in a scientific context than it does in its general usage as a state of confusion, lacking any order. The term "chaos" had been used to describe various forms of randomness, to refer to an apparent lack of order in a system that nevertheless obeys particular laws or rules.

But chaos, being approached scientifically, refers to the issue of whether or not it is possible for someone to make accurate and precise long-term predictions of any complex system if the initial conditions are known to an accurate degree (Oestreicher, 2007).

In the late 1970s, it became specifically linked with the phenomenon of sensitive dependence on initial conditions. By the early 1980s, at least indirect signs of chaos in this sense had been observed in all sorts of mechanical, electrical, fluid and other systems, and there emerged a widespread belief among researchers that such chaos must be the source of all important randomness in nature (Wolfram, 2002).

There was also a conviction that if we knew exactly the laws and rules of nature and the state of the universe at the initial moment, we could precisely predict the state of the same universe at a subsequent moment. But this is not what always happens. Even if the natural laws were completely known to us, we could still only know the state to a very little degree. Here small differences in the initial conditions may lead to huge differences in the final phenomena. A small error in the former will result in an enormous error in the latter. Prediction then becomes improbable, and we have a random phenomenon (Pilloli, 2008).

Edward Lorenz, a meteorologist was the first to talk about a known instance of chaotic behavior; "the first mathematically generated chaos that encountered was produced by using a primitive model of a global weather system." The model would give a rough idea of how real weather behaved. It contained 12 variables. He found out that very small changes in the initial conditions produced widely varying and unpredictable responses (Oestreicher, 2007; Sardar & Abrams, 1999; Kiel & Elliot, 2004). This led to the birth of chaos theory.

Chaos theory is the study of nonlinear systems, in which seemingly random events are actually predictable from simple deterministic equations. The two main aspects of chaos theory are the ideas that systems - no matter how complex they may be - rely upon an underlying order, and that very simple, minor events can cause very complex, major behaviors or events in the results. This latter idea is known as sensitivity to the initial conditions.Small differences in initial states finally combine to produce markedly different end states later on in time. Chaotic systems are extremely sensitive to initial conditions, and even the smallest event can trigger large consequences.

Chaotic systems, though mathematically deterministic, are nearly impossible to predict. Chaos can be sensed better in long-term systems than in short-term systems. Behavior in chaotic systems is also aperiodic, referring to the fact that no variable in a complex system undergoes a regular repetition of values. A chaotic system can actually evolve in a smooth and orderly way. It is one of a set of approaches to study nonlinear phenomena. Specifically, chaos is a particular nonlinear system wherein random events can, in fact, be predictable from simple deterministic equations. Thus, a phenomenon that appears locally unpredictable may indeed show global stability, display clear boundaries and include sensitivity to initial conditions (Retrieved from http://www.psicopolis.com/fisikepsic/caoscompl.htm).

During 1980s, chaos theory came to prominence in the world of research. It deals with systems that apparently obey the normal rules and laws of physical systems, but do so in a highly unpredictable fashion. Chaotic systems can be found in many different domains; examples include the turbulent flow of fluids, irregularities of the heartbeat, growth of certain insect populations, the dripping of a water tap and the collisions of atoms in a gas (Retrieved from http://www.inclusional-research.org/comparisons4.php).

The nonlinear dynamic systems studied by chaos theory are complex systems in the sense that too many independent variables are interacting with each other in too many and varied ways. It concerns itself with environments, organizations or systems that are complex in the sense as very large numbers of constituent elements or agents are connected to or interacting with each other in many different ways. The systems are characterized by continual organization and re-organization of and by these constituents. They have the capability to balance order and chaos (Sardar & Abrams, 1999; MacGill, 2007; Mason, 2008; Lorenzen, 2012).

Complexity theory developed from chaos theory and represents the body of research focusing on these systems that have complex characteristics. Complexity theory deals with systems that display complex global behavior as a result of the local interaction of components, or “agents”, where the behavior of the components is determined by relatively simple rules and principles. Like chaotic systems however, the outcomes of these local interactions may not be linearly influenced by the initial conditions of the system, and so the prediction of the global action of a complex system cannot necessarily be dependent upon an understanding of the behavior of the lower-level components alone. Complex behavior may be found in many different kinds of system, ranging from traffic flows, to cell differentiation, to population dynamics, and turbulence. Complexity theory is concerned with self-organizing phenomena and the effect of one constituent behavior on another. Complexity science is a relatively young science (Levy, 2000; Wheatley, 1993; Mason, 2008; Retrieved fromhttp://www.inclusional-research.org/comparisons4.php).

Why Is Chaos/Complexity Theory Important and Interesting?

- It relates our everyday experiences to the laws of nature by concentrating on relationships between simplicity and complexity and between orderliness and randomness.
- It prevents a deterministic universe which obeys fundamental physical laws, but is capable of disorder, complexity and unpredictability.
- It indicates that predictability is a rare phenomenon due to the rich diversity of our complex world.
- It introduces the possibility of simplifying complicated phenomenon (Sardar & Abrams, 1999).

Where Does Chaos/Complexity Theory Come From?

3 major recent developments have made chaos/complexity a known word:

1. breathtaking computing power that enables researchers to perform hundreds of complex calculations in matters of seconds,
2. an ever-increasing scientific interest in irregular phenomenon(random changes in weather, the spread of epidemic, the rise and fall of civilizations, and
3. the emergence of a new style of geometrical mathematics(Sardar & Abrams, 1999).

By defining chaos/complexity theory, its importance, and its origin, we can draw some conclusions about the following characteristics of chaos/complexity theory;

Sensitivity to Initial Conditions

The behavior of systems with various initial conditions, no matter how similar, diverges to a great extent as time passes. Tiny differences in input could rapidly become enormous differences in the output. A slight change in initial conditions can have wide range of implications for future behavior. A very small cause determines a considerable, huge effect that we cannot fail to see, and so we say that this effect is due to chance. If we knew exactly the laws and rules of nature and the state of the universe at the initial moment, we could precisely predict the state of the same universe at a subsequent moment (Pilolli, 2008). But this is not always so. Even if the natural laws were completely known to us, we could still only know the state approximately. Here small differences in the initial conditions may lead to very large differences in the final phenomena. A small error in the former will result in an enormous error in the latter. Prediction then becomes improbable, and we have a random phenomenon (Sardar & Abrams, 1999; Larsen Freeman, 1997; Retrieved from http://www.informationphilosopher.com).

Nonlinearity

In a linear system, the sum of causes generates a corresponding sum of effects and that is enough to add the behavior of each component to make predictions and judgments about the behavior of the whole system. In such cases, small modifications lead to small effects, while great modifications and changes lead to large effects. In a linear system, a cause of specific strength results in an effect of equal strength. On the other hand, a nonlinear system is one in which the effect is disproportionate to the cause. Nonlinearity means that the output of the system is not proportional to the input of the system, and the system doesn't conform to the principle of additivity, i.e., it may consist of synergistic reactions in which the whole is not equal to the sum of its parts. Nonlinear systems involve powers other than one and are much harder to analyze and we need computer to fully understand them (Sardar & Abrams, 1999; Larsen Freeman, 1997; Mac Gill, 2007).

Periodicity

A period is a time interval characterized by the occurrence of a certain phenomenon or event. A variable is periodic when it repeats its past behavior after the passage of a fixed amount of time interval. On the other hand, aperiodic behavior happens when no variable influencing the state of the system undergoes a completely regular repetition of values. Unstable aperiodic behavior is highly complicated. It never repeats itself and continues to show the effects of any small change and modifications to the system. This makes exact predictions impossible and generates a series of measurements which are random (Sardar& Abrams, 1999; Larsen Freeman, 1997).

Dynamicity

Chaos is a dynamic phenomenon. It occurs when something changes. There are two types of changes:

1. Regular ones (studied by physics and dynamics)
2. Chaotic ones

The study of chaos is considered to be a science of process rather state, of becoming rather than being. Chaotic behaviors change over time, and there exists a large variety of patterns by which this change can occur (Sardar & Abrams, 1999; Larsen Freeman, 1997).

Complexity

Chaotic behavior is termed complex for 2 reasons:

1. Complex systems often, but not always, are consisted of a large number of components of agents.
2. The behavior of complex systems is more than a product of the behavior of its individual constituents. In complex systems, each component or agent finds itself in an environment which is greatly influenced by its interactions with the other agents in system. Each agent is constantly acting and reacting to what the other agents are doing (Larsen Freeman, 1997). The behavior of complex systems emerges from the interactions of its agents with each other; it is not built into any one component.

Complexity can happen in both natural and artificial, man-made systems, as well as in social structures and human beings. Complex dynamical systems may be very great or very small, and in some complex systems, large and small components live together, cooperatively. A complex system is neither completely deterministic nor completely random and it generates both features. The causes and the effects of a phenomenon, which a complex system experiences, are not proportional to each other. The different parts of complex systems are tied to each other and affect one another in a synergistic manner. The level of complexity depends on the character of the system, its environment, and the nature of the interactions between the system's components. The issue is that in the social world and in much of reality, causation is complex. Outcomes are determined not by single causes but by multiple causes and these causes usually interact with each other in a non-additive fashion. In other words, the combined effect is not the sum of the separate effects of each component. It can be greater or less, as factors can reinforce or cancel out each other in nonlinear ways (Sardar & Abrams, 1999; Larsen Freeman, 1997; Levy, 2000; Mason, 2008).

Unpredictability

While chaos may seem unpredictable, it is the onset of the randomness of complex nonlinear systems which is in fact unpredictable. That the randomness will occur is predictable, what is not is exactly when it will happen. So it seems that complex nonlinear systems behave in a regular, orderly manner until a critical point is reached, and then they go chaotic (Larsen Freeman, 1997). A major reason for the unpredictable behavior of complex systems is their sensitivity to the initial conditions. Because we can never know all the initial conditions of a complex system in sufficient details, we can't predict the ultimate outcomes of a complex system. Even very small errors in measuring the state of a system will be augmented dramatically, making any prediction useless (Sardar & Abrams, 1999; Retrieved from http://www.Whatis Chaos Theory FractalFoundation.org.html).

Determinism

Determinism refers to the belief that every action is the outcome of preceding actions. While aperiodic and unpredictable, a chaotic system is deterministic. Due to the instability, aperiodicity, and the sensitivity to initial conditions, the behavior of chaotic systems is not predictable even though it is deterministic. (Sardar & Abrams, 1999; Larsen Freeman, 1997).

Self-organization, open, adaptive

Spontaneous huge restructurings occur in systems that face the forces of entropy and create new regimes of order and structure. Open systems, those which increase in order and complexity, are open to new matter and energy infusion as they evolve. The capacity to selforganize shows that complex systems are adaptive to the changes and modifications. They don’t simply react passively to events; they actively make an attempt to turn whatever happens to their advantage (Larsen Freeman, 1997). Self-organization is sometimes known as "order for free" because systems acquire patterns of behavior without any input from the outside sources (Retrieved from http://www.psicopolis.com/fisikepsic/caoscompl.htm).

Emergence

Emergence is the way complex systems and patterns arise out of a multiplicity of relatively simple interactions between the agents. Some complex systems display these ‘emergence’ features. These systems, which are basically chaotic, or complex, have the capacity to generate patterns that are seemingly non-chaotic or predictable in behavior. For instance, the weather is a chaotic system with emergent properties. Although it is too tough to identify the precise initial conditions that trigger individual weather patterns or to predict the details of an outcome, the global weather system produces some emergent patterns. These emerged patterns such as cloud formation can be used to predict the overall behavior of the system (Larsen Freeman, 1997; Retrieved from http://www.inclusional-research.org/comparisons4.php).

Feedback sensitivity

Feedback refers to a specific feature of any system in which the output or the result affects the input of the system, thus altering its operation. A feedback does not greatly influence a linear system, while it can generate major changes in a nonlinear system. Scientists usually tend to overlook the effects of feedback to create much simpler models that are easier to study and work with. Systems often become chaotic when the feedback is present. A good example is the behavior of the stock market. As the value of a stock rises or falls, people tend to buy or sell that stock. This in turn further affects the price of the stock, making it rise or fall chaotically (Sardar & Abrams, 1999; Valle, 2000).

Fractals

A fractal is a never-ending pattern. Fractals are infinitely complicated patterns that are self-similar across different scales. They are created by repeating a simple process over and over in an ongoing process. Being influenced by the process of recursion, fractals are images of dynamic systems – the pictures of Chaos (Retrieved from http://www.What is Chaos Theory FractalFoundation.org.html). Fractal patterns are extremely familiar, since nature is full of fractals. Trees, rivers, coastlines, mountains, clouds, seashells, hurricanes, etc. are a few examples (Mac Gill, 2007; Mendelson & Blumenthal, 2000).

Chaos/Complexity Theory Concepts

There are several key terms and concepts used in chaos/complexity theory:

Butterfly effect (also called sensitivity to initial conditions): The idea that even the slightest change in the starting point can cause greatly various results or outcomes.

Attractor: Equilibrium within the system. It represents a state to which a system finally settles or a state which attracts a system.

Strange attractor: A dynamic kind of equilibrium which represents some kind of route upon which a system runs from situation to situation without ever settling down (Retrieved from http://sociology.about.com/od/Sociological-Theory/a/Chaos-Theory.htm). Dynamic systems are attracted to paths that can be traced in time and space. Larsen-Freeman (1997) notes that a complex nonlinear system has a strange attractor because although its cycle repeats itself, no cycle follows the same path or overlaps with any other cycle. What is common to all strange attractors is that they have fractal shapes which look like a geometric figure that is self-similar at different levels of scale (Sardar & Abrams, 1999; Larsen Freeman, 1997, Hadidi Tamjid, 2008).

Applications of Chaos/Complexity Theory in Education

The universe is a chaotic place. It is full of uncertainty and it can be extremely difficult to predict exactly what is going to happen at any given time be it the present or the far future. Chaos theory, which emerged in the 1970s, has influenced several aspects of real-life in its short life thus far and continues to impact all sciences in diverse ways. For instance, chaos theory is applied in many scientific disciplines, including geology, mathematics, microbiology, biology, computer science, economics, engineering, finance, algorithmic trading, meteorology, philosophy, physics, politics, population dynamics, psychology, and robotics, and specifically education.

Education is an uncertain, seemingly vague endeavor. Not only is it difficult to exactly predict what will happen in the class each day, it is nearly impossible to make sure what the best course of education for any given person or class may be. The reasons for this are simple. Education is connected to the rest universe and as such is fully subject to the chaos that naturally exists in reality.

Education is forced to deal with chaos/complexity theory. The initial, and all subsequent conditions, are not to a hundred percent known to any given student or class. This chaos can be seen in two ways. First, every class session is uncertain until it occurs. Despite the best developed lesson plans and class management techniques, the class will be subject to an infinite number of possible occurrences and complexities. Second, it is difficult to see the connection between teaching and learning. How can a teacher know what is taught is best for the student's learning in the short and long terms. However, all students are subject to a variety of chaos in their lives at school and in the world. Educators will always deal with uncertainty in both how and what they should teach. Teachers need to prepare themselves for the chaos and accept uncertainty as a natural condition. Teachers cannot control the entire universe. But they can affect the small slice of the universe they reside in despite all the chaos evident in it (Lorenzen, 2012; Claypole, 2011).

Educational systems, institutions and practices display many features of complex adaptive systems, being dynamical and emergent, sometimes unpredictable, non-linear organizations operating in unpredictable and changing external environments (Morrison, 2006). Chaos/complexity theory suggests a movement towards bottom-up development and change, local and institutional decision-making on education, an emphasis on student-centeredness and experiential, exploratory learning, a rejection of tight prescription and linear teaching and learning and a move towards non-linear learning (Morrison, 2008). Complexity theory emphasizes the process rather than the content of learning. Emergence and self-organization can enhance learning development; tightly prescribed, programmed and controlled curricula and formats for teaching and learning, and standardized rates of progression are greatly rejected by complexity theory (Morrison, 2006).

Conclusion

Everywhere around us, within us, and within this universe we experience complexity and diversity. Everywhere around us and within us we experience change, death, and renewal; order and chaos; growth and decay. Everywhere around us and within us we see pattern upon pattern, ever-deepening levels of complexity and variety. The good news about chaos is that it is natural. It is a key constituent of the universe. Chaos may cause uncertainty but it also creates the opportunities that create hope and change. Chaos/complexity theory demonstrates some elements of a ‘good’ theory. Chaos/complexity theory suggests that it will never be possible to control some kinds of system, as their behavior is so complex and unpredictable that it will never be possible to be certain how they will respond (Retrieved from http://www.inclusional-research.org/comparisons4.php). As far as uncertainty and chaos are awaited with acceptance and calmness, confidence is a good approach to chaos within the universe (Wheatley, 1993). An understanding of chaos/complexity theory is crucial to our understanding of educational systems to better meet the rapidly changing needs of our students and teachers. Chaos/complexity theory raises some very significant issues in an educational context, including the consequences of unpredictability for knowing, responsibility, morality and planning; the significance of non-linear learning organizations; setting conditions for change by emergence and self-organization; the role of feedback in learning; changing external and internal environments; it emphasizes on the fact that schools and learners as open, complex adaptive systems; cooperation and competition; pedagogy; and the significance of context (Morrison, 2006).

References

Claypole, M. (2011). Bring chaos theory to English language teaching. *Guardian Weekly*, July.

Hadidi Tamjid, N. (2008). Chaos/ complexity theory in second language acquisition.*Novitas-Royal*, *1*(1), 10-17.

Kiel, D. L. & Elliott, E. (Eds.) (2004).*Chaos Theory in the Social Sciences: Foundations and Applications.* US: The University of Michigan Press.

Larsen-Freeman, D. (1997). Chaos/complexityscience and second language acquisition.*Applied Linguistics*, *18*, 141–165.

Levy, David L. (2000) *"Applications and Limitations of Complexity Theory in Organization Theory and Strategy"*, in Jack Rabin, Gerald J. Miller, and W. Bartley Hildreth (editors), Handbook of Strategic Management, Second Edition (New York: Marcel Dekker)

Lorenzen, M. (2012).Chaos Theory and Education. Retrieved from http://www.information-literacy.net/2008/04/chaos-theory-and-education.html

Mac Gill,V. (2007). *Chaos and Complexity Tutorial*. Retrieved from http//complexity.orconhosting.net.nz/intro.htmlMason, M. (Ed.) (2008). Complexity Theory and Philosophy of Education. UK: John Wiley & Sons Ltd.

Mendelson, J. & Blumenthal, E. (2000).*Chaos Theory and Fractals*. Retrieved from http://www.mathjmendl.org/chaos/index.html

Morrison,K. (2006). Complexity Theory and Education. APERA Conference 2006, 28 – 30 November 2006 Hong Kong

Morrison, K. (2008). Educational Philosophy and the Challenge of Complexity Theory. *Educational Philosophy and Theory*, 40(1), 19–34.

Oestreicher C. A. (2007). History of chaos theory.*Dialogues ClinNeurosci*.9, 279–289.

Pilolli, M. (2008).*A dynamical system approach to data assimilation in chaotic models*. (Dissertation thesis)

Sardar, Z. & Abrams, I. (1999).*Introducing Chaos*. UK: Icon Books Ltd.

Wheatley, M. (1993).Chaos and Complexity: What can Science Teach? *OD Practitioner*.

Wolfram, S. (2002).A New Kind of Science. *Wolfram Media, 971*.

http://www.psicopolis.com/fisikepsic/caoscompl.htm
http://www.informationphilosopher.com
http://www.inclusional-research.org/comparisons4.php
http://sociology.about.com/od/Sociological-Theory/a/Chaos-Theory.htm
http://www.What is Chaos Theory FractalFoundation.org.html