# THEORETICAL EXPLANATION OF THE IMPLICATIONS OF COMPLEX SYSTEMS THEORY FOR TEACHING SCIENCE

**Parvin Bazghandi, Saeid Zarghami-Hamrah,**
**Yahya Ghaedi, Alireza Mahmudnia**
Kharazmi University, Tehran, Iran
E-mail: pbazghandi@gmail.com, zarghamii2005@yahoo.com,
yahyaghaedy@yahoo.com, alirezamahmmudnia@yahoo.com

**Khosrow Bagheri Noaparast**
Tehran University, Tehran, Iran
E-mail: khosrowbagheri4@gmail.com

## Abstract

*The present study seeks to explain the implications of triple levels of the complex systems theory, as a theory about nature, science, and education, for teaching science. The study has been conducted within a philosophical approach. On the first level, the characteristics of complex systems theory about nature including: top-down character, non-linear interactions, emergence, irreversibility, self-organization, modularity, hierarchy, adaptation and bifurcation are explained. In this regard the point to be mentioned is that the teachers could facilitate the students' understanding from the fundamental features of nature by offering diverse and suitable examples. On the second level, the complex systems theory mainly addresses the nature and methodology of science. Regarding the nature of science, scientific knowledge is defined as condition-structured knowledge and regarding the methodology of science, this theory highlights the features including condition-dependent generalisation, condition-dependent laws, condition-dependent explanation, condition-dependent confirmation, and the limitations of model-centered confirmation. The implications from this level of complex systems theory for teaching science encourage the teachers to clarify the methodology of science for the students. Regarding the third level, Complex systems theory orients attentions toward dynamic, complicated, and integrated levels, including the neurological, the experiential, the contextual/material, the symbolic, the cultural, and the ecological levels of education. So teachers might explain the basic features of the natural events through non-linear and holistic methods in teaching science.*
**Key words**: *science education, teaching science, nature, complex systems theory.*

## Introduction

Science education and its shortcomings are significant issues which have gained international importance. Due to the importance of such issues, numerous international studies are being conducted including the studies by IEA, regarding the manner of education and evaluation for science and mathematics known as TIMSS, which have been led from 1995 up to the present time. So the importance of science education and its challenges have led to a bulk of studies investigating this topic (for example: Fraser & Tobin, 1988; Mintzes & Leonard, 2006; Abel & Lederman, 2007; Fraser, Tobin & McRobbie, 2012). Among them there are studies that incorporate philosophy and the nature of science and suggest a revision in science education according to these bases (for instance: Scheffler, 1992; Matthews, 1994; Tobin and McRobbie, 1997; McComas, 1998; Peters, 2006; Niaz, 2009). For instance, Matthews (2000) believes that teaching science should not be limited to the transmission of scientific facts, but it should aim at developing a scientific mentality in the learners, that is, the same as the mentality

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of well-known scientists such as Aristotle, Archimedes, Newton and Einstein. This does not mean to expect the learners to be prominent scientists, but it means that instead of transmitting scientific data we should develop a scientific mentality in learners so that they can attain a more complex and complete understanding of science and above this goal their epistemological awareness would be developed throughout their lifetime. As Matthews holds, by stepping into this path some questions arise in the field of teaching science (pp. xvi-xvii): what is a scientific explanation? Who do models function in science? How much confirmation does a hypothesis require before it is established? We might add the other philosophical questions about science to these questions: what is science? And what is the scientific method?

From a more general point of view, it seems that science education is related to different perspectives in the field of philosophy of science. Clarifying on the same issue, Clark (1989) explains that certain philosophical perspectives on subject matters create necessities that affect what the teachers do and the methods of teaching that subject matter. For example, according to a view in the philosophy of mathematics, mathematical facts are analytical statements. If this philosophical view is taken as hypothetical by the math teacher, in this case mathematics cannot be taught with the same method as the science which is taught based on hypothesis and experiment. Therefore, it cannot be taught in a "mathematics lab". Clark also believes that if we adopt the views by Bacon, Kuhn, or Popper, the method we use for teaching science would not be indifferent toward these philosophical underpinnings.

On this basis, it can be said that there is a more general relationship between philosophies of science and teaching science. Philosophers of science have constantly been attempting at illuminating the nature of science and the process of origination and development of sciences throughout the history. Subsequently, understanding their ideas can illuminate the nature of science and the manner of its development. This awareness contains many lessons for teachers and learners who are in search of knowledge and science and it can guide them in their journey to search science.

On the other hand, in an attempt to evaluate the present educational realities, McComas and Olson (1998) state, that most of scientific instructions are around the body and terminology of scientific knowledge and overlook the nature and philosophy of science, which is considered a serious failure in science education.

Some of the thinkers and researchers suggest that this common shortcoming in teaching science in a variety of societies and countries would create adverse and negative consequences in the society. For example, McComas, Clough and Almazroa (1998) refer to the findings obtained by the significant and extensive research in American society which showed that although the Americans are interested in science, the majority of the social members have no clear idea of what science is and how it functions. Discussing the destructive consequences of such a shortcoming, they state that:

> "This lack of understanding is potentially harmful, particularly in societies where citizens have a voice in science funding decisions, evaluating policy matters and weighing scientific evidence provided in legal proceedings. At the foundation of many illogical decisions and unreasonable positions are misunderstandings of the character of science"(P.3).

This inadequacy in the process of science education might have multiple reasons. As McComas, Clough and Almazroa (1998) explain, Americans receive no education about the nature of science in schools and during the process of teaching science; hence they have no adequate understanding of science. One of the primary reasons might be explained by the fact that in most of the cases the science teachers have no deep and adequate understanding and awareness of the nature and philosophy of science. For example, Lederman (2007) explains that many studies indicate that the teachers' knowledge about the nature of science is inadequate and even wrong and this could be one of the main reasons for the ineffectiveness of science education.

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In this way, raising the teachers' awareness and improving their attitudes regarding the nature of science could enhance the conditions for teaching science as well. In line with this claim, Abd-El-Khalick (2005) explains in his study that the teachers who get familiar with the nature of science and how it is developed are more successful in teaching science.

Other relevant studies reveal that many science textbooks in different countries provide the students with a vague, even wrong, picture of the nature of science which does not conform to the emerging and more complete attitudes about the nature of science. This weakness might explain other relevant shortcomings and inefficiency in teaching science. For instance, McComas and Olson (1998) mention the results of the study by Bentley and Garrison which show that the ideas presented in many science textbooks in schools about the nature of science are naive, incomplete, and ignorant of novel views on the nature of science and finally they might even be wrong.

In this manner, it could be said that the discussions of philosophy and nature of science are either overlooked, or inaccurate picture is provided in the science curriculum in the current conditions. This shortcoming would lead to negative consequences, some mentioned earlier, and create considerable challenges for teaching science which require more consideration and finding possible practical solutions. Since, the pictures and understandings that the science teachers have in mind would influence the type and process of their teaching, now we might raise the questions of what are the new emerging attitudes regarding the nature of science? And what are the outcomes and necessities of these attitudes for teaching science?

One of the emerging attitudes might be originated from the changes occurred in the theoretical and philosophical ideas regarding the nature of science and the manner of progress in late 20th and early 21st centuries. These changes and evolutions have motivated the thinkers to theorize accordingly and suggest definitions and features for the theories under a variety of titles including systems theory, chaos theory, complexity theory, and the theory of self-organizing systems (for example see: Lewin, 1993; Rescher, 1998; Doll et al., 2005; Wegener, 2005; Morrison, 2008; Hooker, 2011). However, Goldman (2007) recommends that the complex systems theory could be considered as a more appropriate term for naming this perspective and the relevant views.

Complex systems theory emerged as a reaction to the simplicity, reductionist or atomistic approach toward explaining the nature and different dimensions of the natural life as well as social life and in order to explain the real complexities of the natural and social systems.

As Mason (2008) argues, the complex systems theory has been developed in response to the dominant reductionist views in the field of natural science. According to the reductionist view, the nature and the natural phenomena could be explained through explaining their elements, and ultimate particles (p. 33). The complex systems theory rejects such explanation of nature as conforming to the reality of the nature and the natural events. This theory defines a systematic essence for the nature and believes that we need to regard the wholes and the systematic essence of the natural events, hence the interrelationships among the elements, for explaining the nature and natural events. Goldman (2007) refers to the simplistic view toward the nature as *atomistic* approach and suggests that from this point of view, the different parts of the nature need to be studied separately and independent from each other because the interrelationships among the different parts and elements in the natural phenomena are examined as side issues and take no high priority in explaining the natural events. He indicates that from mid-twentieth century, the researchers and thinkers from a variety of scientific fields provided experimental documents showing that we need to understand that the nature is not made up from fundamental units. According to this view, nature is comprised from systems which create the foundation for complex systems theory which seeks to explain the nature. As some of the researchers suggest, after that, this different view about the nature and the natural sciences has been introduced to other fields of science, including social sciences and education (for example: Mason, 2008; Davis & Sumara, 2006; Khattar, 2009).

If the teachers adhere and refer to the simplistic view which lacks a comprehensive picture of the complexities of nature, science, and education, the students do not identify and understand the systematic essence of the nature and obtain an incomplete, even inaccurate, picture of the science which creates educational challenges and barriers discussed above. Now, drawing to this view and the complex system theory in natural and social sciences, we might raise the question of how this theory affects the teaching practices of the science teachers.

Consequently, the present study seeks to find the possible answers to these questions: what are the origins of the complex systems theory and how could this theory be employed in teaching science? In this regard, this research is supposed to fill the existing research gap about “science education”. The previous studies have investigated “nature” and “science” as complex systems which has led to the emergence of new types of philosophies of nature and science (for instance: Rescher, 1998; Leiber, 2001; Lenk & Stephan, 2002; Hooker, 2011). On the other hand, other studies conducted in the field of “education” include variety of complex systems (for instance: Doll et al, 2005; Conrad, 2006; Davis & Sumara, 2006; Osberg & Biesta, 2010). This study draws on the complex systems theory in order to provide the grounds for inferring implications for teaching science.

## Methodology of Research

The present study is conducted within a philosophical approach. Nonetheless, due to the diversity of the methodologies in the field of philosophy (Given, 2008; and Heyting, 2005), the method (or methods) employed must be selected according to the specific goals that this study seeks to serve.

In the study, the complex systems theory was analyzed and employed on three levels for addressing the first research question (what are the origins of the complex systems theory?): first, as a theory about nature, second, as a theory about science; and third, as a theory about education. As Erduran (2009) also highlights, such theoretical inquiries might provide the context for deducing implications for education. So the logico – deductive approach was also used as one of the syllogism methods (Haggerson, 1991) with the aim of deducing general principles in the three different levels which guide teachers in teaching science. This method is the same as practical syllogism, presented primarily by Aristotle, which provides the possibility to inference the prescriptive statements from descriptive statements.

## Complex Systems Theory as a Theory about Nature and Teaching Science

The complex systems theory was generally introduced with the purpose of explaining the nature and functions of natural systems. It concerns itself with environments, organisations, or systems that are complex in the sense that very large numbers of constituent elements or agents are connected to and interacting with each other in many different ways. These constituent elements or agents might be atoms, molecules, neurons, etc. Whatever the nature of these constituents, the system is characterised by a continual organisation and re-organisation of and by these constituents into larger structures through the clash of mutual accommodation and mutual rivalry. Thus, molecules would form cells, neurons would form brains, and species would form ecosystems, and so on. At each level, new emergent structures would form and engage in new emergent behaviours. So according to this theory, the natural systems are characterized with emergent behaviors which inspired Mason (2008) to call complexity as a science of emergence.

As Alhadeff-Jones (2008) mentions, the notion of complexity refers to the quality or condition of being complex. The terms ‘complex’ and ‘complexity’ are usually used as the opposite of simplicity. By the same token, Goldman (2007) clarifies in Simplistic thinking each part of nature can be studied in isolation from its relationships to any other part. The important thing is to identify, to make an inventory of all of the fundamental bit in nature and their properties, and then we will be able to synthesize nature out of those bits. So simplistic thinking has a bottom-up Character. But complex systems theory says, because even though it looks like the parts in this system, are the same as the parts in that system, parts in a system must be analysed only in relation to the way they fit into the whole. To understand a system we have to understand the functioning of the whole. It is needed to know from the beginning what the function of this system is, how it operates, how it's supposed to operate in order to understand whether the individual parts are properly designed, properly functioning, and have the proper relationship to one another. Thus complex systems theory has a top-down character.

In this regard, Davis & Sumara (2006) mention, researchers have identified several necessary qualities that must be manifest for a natural phenomenon to be classed as complex. Some of the qualities they refer to include (pp. 5-7): Self-Organized; and Nested Structure or scale-free networks (fig. 1); Nested structure indicates that complex unities are composed not just of smaller components (circles), but also by the relationships among those components (arrows). These interactions can give rise to new structural and behavioural possibilities that are not represented in the subsystems on their own.

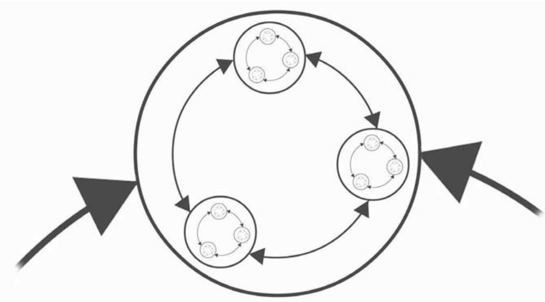

**Figure 1: The nestedness of complex unities.**

Pertaining to the points raised above, the complex systems theory defines characteristics such as emergence, self – organization, and nestedness as the features of natural phenomena and systems. Regarding the same discussion, Hooker (2011) suggests some other characteristics mentioned in the following in the order of appearance (pp. 20-40): Non-linear interactions, emergence, irreversibility, self-organization, modularity, hierarchy, adaptation and bifurcation. He argues that, in a linear system, there is a linear relation between causes and effects (small causes have small effects) but in a nonlinear system this is not necessarily so; small causes may have large effects. Self-organisation occurs when a system bifurcates to a form exhibiting more order and/or more complex behaviour. Emergence is the central characteristic of a system. The system has properties that are not possessed by its parts. The parts have properties, and those parts interact with the other parts, but they do not have the properties that the system possesses. Hierarchy proper is asymmetry of level (vertical) control in a sufficiently modular system. Modularity is one form of system composition, that is, of the relationship(s) between parts and whole. An organism is adapted when it possesses an autonomy-satisfying set of traits in its life-environment.

A process that is reversible can be run backwards while still satisfying the same laws. Classical dynamics is time-reversible in this sense. Every dynamically possible process running forward is equally possible running backwards. But virtually all real processes cannot be run in reverse. Many, not all, examples of complex dynamics, but all those concerned with living systems, are of this kind. Finally, a bifurcation occurs when a structural instability in a system leads to a change in its dynamical form, that is, a change in the structure of its attractor landscape.

After discussing about the ideas that complex systems theory presents regarding nature's characteristics and phenomena, we turn to the implications and application of this theory for teaching science. The first point to be raised is that science seeks to explain the natural phenomena and events; therefore, nature and its events make up the content of science and the specific perspectives that address the nature and the qualities of the natural systems and events provide the teachers with fresh definition of science. The complex systems theory includes practical implications for teaching science. According to this theory, it seems necessary for the teachers to focus on the characteristics such as emergence, non-linear interactions, irreversibility, self-organization, modularity, hierarchy, adaptation and bifurcation in presenting an image of natural events for the students.

The second point to be mentioned is that the teachers could facilitate the students' understanding from the fundamental features of nature by offering diverse and suitable examples. This class of examples, available in different fields such as physics, chemistry, biology, and geology for explaining the specific features of the scientific fields, could provide ideal educational options for teachers to enrich the process of teaching science. For instance, Goldman (2007) mentions the sodium chloride molecule as an example for explaining emergence in the nature and the natural systems:

> "A simple molecule like sodium chloride has an emergent property that neither sodium possesses nor chlorine possesses. That's pretty obvious, since chlorine is a toxic gas, sodium is a metal that reacts explosively with water, and yet when you put sodium chloride into your blood, which is mostly water, then it doesn't explode, and the gas that is chlorine does not bubble through your body and harm you. So sodium chloride has properties that are not present and could not be predicted from sodium by itself or chlorine by itself" (p. 97).

This kind of simple and comprehensible examples could help the teachers to represent the emergence feature in nature to the students.

## Complex Systems Theory as a Philosophy of Science and Teaching Science

The philosophers and thinkers in the field of the philosophy of science have been constantly concerned with addressing the science relevant questions and offering possible answers to these questions: What is science? What is scientific explanation? What is the method of science? And etc.

Although complex systems theory initially has been a theory about nature but some studies have been done to introduce the theory of complex systems as a philosophy of science (for instance: Leiber, 2001; Hooker, 2011). From Hooker's viewpoint, some of the philosophies of science like positivism took simplistic approach by focusing on a scientific method as logical inference: logical induction from the data to form the theory, deduction from theory for prediction and explanation (Reduction to fundamental laws and separate contingent initial conditions became the basic explanatory requirement), and deduction from data that conflict with prediction to a falsification of the predicting theory. But complex systems impact every aspect of a science, from what counts as evidence, through basic theoretical concepts of component, interaction, organisation and self-organisation to deep limits on prediction and control and the relations of laws, explanation and the methods of science (Hooker, 2011). In this regard, Davis and Sumara (2006) also believe that the word science is usually taken to refer to both a collection of established principles on the nature of the universe and the particular methods of investigation and verification by which those principles are established. These methods, at least in the manner that they are most commonly presented, are organized around the standard of proof through replication: "Hypotheses become facts and theories become truths as researchers are able to demonstrate that predictable and repeatable results can be obtained"(P.17).

However, it turns out that neither the logical or the methodological situation is so simple; both scientific practice and rational method are, and must be, much more complex than this (Hooker, 2011, p. 841).

Correspondingly, Fullan (1993) argues that the complexity attitude takes a different approach toward presenting a notion of science compared to the traditional philosophies of science. The traditional philosophies of science define scientific explanation as the clarification of the basic cause-effect relations; however, in the complexity approach the same simple cause-effect relations produce complex results. Therefore, although the complexity is rooted in the basic cause-effect rules, the significant point to be highlighted is that these rules do not predict the results for every scientific phenomena and situations. Therefore, despite employing the basic and universal cause-effect rules, the results are not universal and various situations lead to different results.

According to the abovementioned issues, clarifying the nature of scientific knowledge is considered as the first step in explaining any philosophical theory about science. The second step includes addressing the science from ontological and epistemological dimensions in the given philosophical theory.

As Hooker (2011) believes scientific knowledge is the knowledge with conditional structure which is condition-bound and undergoes alterations when the conditions change. In this fashion, Lansing (2002) speaks of a new way of investigating the fundamental nature, types and conditions for functional integration in a society.

In the next step, in the complex systems theory as a philosophy of science the ontological relevant elements could be explained in two categories: the nature of its fundamental constituents or components and the nature of its internal features (Hooker, 2011, pp. 862-875): Regarding the nature of their fundamental constituents or component it could be said that science maintains basic components and exhibits a systematic nature. And regarding the nature of science internal features we might mention the features such as emergence, condition-dependent laws, determinism, causality, and unification.

Finally, regarding the epistemological elements of a complex systems philosophy of science, Hooker (2011) argues that general philosophical discussion of laws, explanation, confirmation and the like are set aside here in favour of issues of more particular relevance for complex systems (p. 878-895): A-Condition-dependent generalisation; B-Condition-dependent laws; C-Condition-dependent explanation; and D-Condition-dependent confirmation.

Regarding the educational implications inferred from the second level of complex systems theory discussed in the present study, as a philosophy of science, we might refer to the following points. First, the complex systems theory in this level largely addresses the nature of science and scientific methods. This theory introduces the scientific knowledge as condition-structured knowledge for illuminating the nature of science and besides supporting causality and determinism for the scientific methodology; it highlights specific features including condition-dependent generalisation, condition-dependent laws, condition-dependent explanation, and condition-dependent confirmation.

These characteristics are not limited to particular scientific content and seek to shed light on the methodology of science. Therefore, it could be said that the implications of this level of complex system theory for teaching science are related to the methodology of science rather than the content. Consequently, the science teachers could explain to their students that accepting causality and determinism does not conflict with supporting the condition-dependent nature of scientific explanations and scientific knowledge. On the other hand, they might refer to the abovementioned features while informing the students about the nature of science and its methodology. For instance, the teachers could refer the students to the history of science and indicate how explanation and generalization have been condition-dependent and affected by the changing conditions. In similar manner, the scientific rules are far from definite and historical and depend on conditions and undergo changes during the historical periods. This perspective challenges the traditional view that defined relationships between hypotheses, theories, and laws. McComas (1998) suggests that according to the traditional and inadmissible idea about science: “hypothesis becomes theories that in turn become law” (p. 54). In addition, Lederman (2007) highlights that there is a widespread, simplistic, and even inappropriate belief that takes the relations among the theories and laws as a hierarchical structure; that is, the theories evolve to laws depending on the amount of supporting evidence. In this sense, the laws maintain higher ontological position compared to that of the theories. Trying to correct and revise this interpretation, Lederman argues that laws and theories are two districts representations of science which could not transform or improve to one another. The laws are the descriptive predicates of the relations among the phenomena observed. For example, the Boyle–Mariotte law describes the relation between the pressure and volume of gas at constant temperature. On the other hand, the theories are deduced explanations for observed phenomena. As an example, the kinetic molecular theory offers an explanation for what Boyle–Mariotte law and Charles and Gay-Lussac Law describe. Along these lines, the distinct implication of complex systems theory for teaching science is that the teachers could use the relevant scientific examples in order to reveal the condition-bound nature of scientific theories and laws and the possible changes during the history to the students.

## Complex Systems Theory as a Theory about Education and Teaching Science

Complex systems theory has been entered into different fields of studies including education. As Davis and Sumara (2006) refer, complexity thinking not only enables but compels attentiveness to the roles of researchers in contributing to the shapes of the phenomena researched. This is a particularly important issue for educators. They add that:

> "Complexity thinking within education is oriented toward the means by which humanity seems to have transcended its biological limitations. Some principal sites of inquiry oriented in this way are studies that focus on language, writing, mathematics, and other technologies that enable groups of individuals to couple their perceptions and consciousnesses, in effect, creating grander cognitive unities–collective intelligences–whose possibilities simply cannot be determined in terms of the summed capacities of individuals." (P. 26)

On the other hand, for describing the focal result of complexity for knowledge, Peters (2008) believes that complexity, as an approach toward knowledge, has facilitated the emergence and development of platforms such as Web 2 and semantic Web, algorithms, and digitalization procedures that reinforce openness as a value in the field of science formation and development. He writes:

> "This seems to intimate new orders of global knowledge systems and cultures that portend a set of political and ethical values such as universal accessibility, rights to knowledge, and international knowledge rights to research results especially in the biosciences and other areas that have great potential to alleviate human suffering, disease and high infant mortality. Openness seems also to suggest political transparency and the norms of open inquiry, indeed, even democracy itself as both the basis of the logic of inquiry and the dissemination of its results" (p. xiii).

One of the major representations of such openness could be found in the reconceptualization of education. For instance, according to complex systems theory and regarding the questions like: How does the brain work? What is consciousness? What is the role of emergent technologies in shaping personalities and possibilities? How do social collectives work? What is knowledge? And what is education for? Davis and Sumara (2006) argue that brains, social collectives, bodies of knowledge including science and so on, as complex systems, and their sub-components or agents, are working along with each other. In other words, that brains, social collectives, bodies of knowledge including science and so on, as complex systems, and their sub-components or agents are working together and the entire story is named education. To make sense of the sorts of phenomena, one must "level-jump"– that is, simultaneously examine the phenomenon in its own right (for its particular coherence and its specific rules of behaviour) and pay attention to the conditions of its emergence (e.g., the agents that come together, the

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contexts of their co-activity, etc.). Complex systems theory prompts this level-jumping between and among different layers of scientific organization, any of which might be properly identified as complex and all of which influence (both enabling and constraining) one another. Complex systems theory also orients attentions toward other dynamic, complicated, and integrated levels, including the neurological, the experiential, the contextual/material, the symbolic, the cultural, and the ecological. As Davis and Sumara (2006) believe, each of these levels/phenomena can be understood as enfolded in and unfolding from all of the others. For instance, science cannot be understood without considering social movements and societal obsessions, or in ignorance of the subjective interests and personal histories of individual scientists. (p.26)

After discussing the details of complex systems theory, some of the implications of this theory are presented as a theory for teaching science. The first point to be underlined is that there is a common and broad consensus that teaching science involves a subjective understanding of the current scientific and objective knowledge. However, according to the complex systems theory, understanding the learning process requires adopting a holistic view which takes into account the micro and macro dimensions along with each other. For further illumination about the same discussion, we might refer to the ideas raised by Christensen and Fensham (2012). They believe that teachers' responsibility in the classroom is not restricted to introducing the scientific phenomena to the students. Rather, they need to take a multi-disciplinary approach toward encountering the students with real life issues and adopt a socio-scientific stance as well. Christensen and Fensham state that:

> "Engaging with socio-scientific issues effectively in science classrooms will require science teachers to encourage students to express and examine different views of a problem and to place scientific knowledge in its broader multi-disciplinary context" (p.756).

Along these lines, Davis and Sumara (2006) suggest a model for providing a comprehensive image of different layers and aspects in the process of learning science. As one implication, the teachers should be encouraged to assume a holistic view which necessitates the science education to consider science in a multi-disciplinary context and within the broader social, historical, and cultural setting which surround the scientific realities.

As a final point, the complex systems theory as a theory for teaching science puts emphasis on developing the uncertainty, flexibility, unpredictability, and open mentality in the students. As Iannone (1995) underlines, science possesses a non-linear, indefinite, unpredictable, and chaotic nature according to the complex systems theory, which allows to open horizons and variable possibilities for scientific knowledge. Therefore, this theory invites the scientists and science experts to keep these features in mind in their practices. As a result, this theory recommends that for developing a scientific mentality in the students, the teachers need to respect and show consideration for these features.

## Conclusions

The present study investigates the implications obtained from the triple levels of the complex system, as a theory about science, nature, and education, for teaching science. These three levels involve effective implications for teaching science with a specific method which the present study aimed to introduce.

In conclusion, the complex systems theory as a theory about nature is concerned with the content of science, while it focuses on the methodology of science as a philosophy of science. In this manner, the complex system theory in two discussed levels involves implications for presenting the content, nature, and methodology of science in teaching science. This theory on the third level discussed in the present study, as a theory about education, seeks to re-conceptualize the nature of teaching and reveals some details for the manner of teaching. For that reason, the three levels defined for complex systems theory in this study seemingly are complementary. This theory could provide a novel understanding of teaching science by introducing a new stance about the nature, methodology, and content of science on the one hand and the meaning and components of teaching on the other hand.

To mention some of the aspects of this new understanding we might refer to explaining the basic features of the natural events such as top-down character, non-linear interactions, emergence, irreversibility, self-organization, modularity, hierarchy, adaptation, and bifurcation. Other implications include uncertainty and employing the non-linear and holistic approaches and methods in teaching science.

## Note

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*Advised by Agnaldo Arroio, University of Sao Paulo, Brazil*

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| ***Parvin Bazghandi*** | Ph.D. Student, Kharazmi University, Tehran, Iran.<br>E-mail: pbazghandi@gmail.com |
| ***Saeid Zarghami-Hamrah*** | Faculty Member of Kharazmi University, Tehran, Iran.<br>E-mail: zarghamii2005@yahoo.com |
| ***Yahya Ghaedi*** | Faculty Member of Kharazmi University, Tehran, Iran.<br>E-mail: yahyaghaedy@yahoo.com |
| ***Alireza Mahmudnia*** | Faculty Member of Kharazmi University, Tehran, Iran.<br>E-mail: alirezamahmmudnia@yahoo.com |
| ***Khosrow Bagheri Noaparast*** | Faculty Member of Tehran University, Tehran, Iran.<br>E-mail: khosrowbagheri4@gmail.com |