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Innovation and Creativity From the Viewpoint of Systems Thinking and Chaos Theory

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ABSTRACT

One of the most demanding tasks of the future will be to provide for a sustainable development of *GAIA*. As long as humankind is only focussed on the demands of humankind without being aware of the demands of GAIA as such - with other species and plants not necessarily directly connected to the welfare of humankind - true sustainable development is impossible.

Humankind is required to work creatively on new and more appropriate ways to cope with the demands of the present and the future. To do so, the generation of *sustainable innovation* based on a systems point of view becomes a prerequisite.

Hence, there are two mains fields of application for systems thinking: the field of understanding a considered system and the field of creatively finding solutions for a considered system. Since such systems mostly behave dynamically and the process of creative collaboration most often shows chaotic instead of purely deterministically structured and predictable patterns, the major question in this contribution is to consider nonlinear dynamic systems thinking respectively chaos theory accessible to the generation of innovation and creative problem-solving.

Keywords: systems thinking, chaos, nonlinear dynamic systems, creativity, sustainable innovation

1. INTRODUCTION

We touch different parts of the same beast and derive distorted pictures of the whole from what we know: 'The elephant is like a snake,' says the one who only holds its tail; 'The elephant is like a wall,' says the one who touches its flanks [1].

With this fable of the blind men and the elephant Wehner, Csikszentmihalyi, and Magyari-Beck exactly describe what many attempts within creative problem-solving and the generation of innovation are often about. As a specific form of nonlinear dynamic system this is certainly also true for the generation of innovations for a sustainable development of systems of any kind, including that of GAIA. In order to seriously work on sustainable soltutions a broader view becomes obsolete. Otherwise the focus on subsystems and single issues can at the best only provide for temporarily second-best solutions for the subsystem or single issues. Instead, for the overall system the action taken based on the restricted perspective might also be harmful. Further, the long run effects for the subsystem are highly likely to be destructive, since the interplay with other parts of the overall system have not been taken into account.

2. SUSTAINABLE DEVELOPMENT OF GAIA

One might argue that the development of GAIA as such is in many ways philosophical or something that is necessary to be handled on large-scale levels such as on the international stage by the UN and the national governments. In the sense of systems dynamics this chain of thoughts seems to be dangerous and even disastrous as the following example in the field of education shows.

In the example there is a teacher in a tiny school in a rural village named Nowhere with few inhabitants, 1000 kilometres away from the next city. The people are merely living from goods they produce themselves, providing services for their own community without crucial dependencies on the cities; the inhabitants live in an economically and technically nearly autarch system. Within the school there are only two teachers, Mrs. Focus and Mrs. Gaia. Both care very much for the pupils they teach; therefore they meticulously think what issues they should stress in class. Since the village is that small and detached from the rest of the world Mrs. Focus decides to base her teaching on values and mechanisms for the community of the village. On the other hand, Mrs. Gaia is aware of the peculiarities of their village, but she is also thinking about the country as a whole and about other countries and the entire world. Though she is not actually aware about strong direct connections between their village and the outer system at the various levels, she is convinced that everything influences everything, sometimes hidden and sometimes revealed in the long run. Since both women are wonderful and caring teachers and the pupils are themselves very open-minded, curious, and hard working members of the society, the children develop very well. So it comes to pass that there is one girl in Mrs. Focus' class and one girl in Mrs. Gaia's class who are performing so well that after having finished school they both get a scholarship at one of the most outstanding universities in the country. Both also finish their university education in a minimum time by being both strongly concerned about public and political affairs. Both have a wonderful carreer and get surprisingly nominated by two different parties for the position of the president of their country. All of a sudden the village of Nowhere indirectly not only has tremendous influence on a whole country, but also affilitated countries. This brings up several questions of interest with respect to the influence of the education at school on issues such as the governing of a country: What kind of influence does the eduction at school have on the value system and the capabilities of the two potential presidents? How strongly did the specific forms of education determine the further development of the two young women? How did the educational influence correlate with other influencing patterns, including environments and communities, which the two ladies came in touch with? And most interestingly - who will be the better president for the country, also in respect to related countries depending directly or indirectly on actions taken by the country?

Although systems do not seem to be strongly interdependent and with little or even no observable impact on the environment at the present, that does not reveal much about the future direct influence and especially indirect influence of actions taken within a system on other systems and its environment. As this simplified example pointed out, sustainable considerations are of interest for every system, no matter the scale and size.

3. SYSTEMS CHARACTERISTICS OF SUSTAINABLE INNOVATION

Innovation is a means to provide for an improvement of a certain system - such as a product, a process, an organizational or social structure - by providing system-related new solutions. Or, in the words of West and Richards, *innovation is the introduction of new and improved ways of doing things at work* [2]. Therefore, *creativity* is crucial in order to generate the so-called new or invention. But an innovation is more than invention by considering not only the generation of the new but also the implementation of the new into the market or into the society. Hence, not only the generation of the new but also the implementation needs creativity.

Sustainable innovation is innovation that is sustainable from an ethical, a social, an ecological, and an economic point of view, but not only with regard to humankind but with regard to GAIA as a whole, with humankind in a key role [3].

Nonlinear dynamic systems are the core interest of chaos research. A typical example for that are the various forms of innovation, from product innovations, process innovations to structural and social innovations. There are two main reasons of the creation of innovation: firstly, it can be the answer to a demand on the market or the society in general (= *demand-pull innovation*) or, secondly, it can be an initiative itself in order to create its own demand on the market or in the society (= *technology-push innovation*) [4, 5]. A further distinction is about the degree of innovation; whereas an *incremental innovation* stands for an improvement of already existing concepts by relying on the used processes in their application, a *radical innovation* leads itself to tremendous changes in the behavior of the applier [6, 7].

Especially the last distinction makes a big difference with regard to the development patterns of a system in general: starting from the other way round, the implementation of the market is connected to a high degree of *uncertainty* and *unpredictability*; but in contrast to incremental innovation for radical innovation we do not know exactly who the potential customer group is. It becomes obvious that traditional deterministic means of investigation, such as inquiries of an unknown or at least badly known group of customers, are needless.

Incremental innovations, but especially radical innovations, show a nonlinear dynamic system behavior, but to a different degree. That means that discontinuous, inhomogenous, and aperiodic attributes usually have a higher impact within radical innovations. Nevertheless, it is the *interplay between determinism and chaos, structure and flexibility, and convergence and divergence* that are needed for those systems to function.

3.1. Sustainable Innovation

Going now a step further, how can innovation contribute to sustainable development and what makes an innovation itself sustainable? Sustainable development is not stable and is also not just the answer to changes in the environment. Instead it has to be stressed that *sustainable development is itself dynamic* with changing patterns as a core characteristic. Hence, based on Varela and Maturana *self-stimulation* and *internal feedback* are mechanisms of systems with *autopoietic character* and are responsible for the *self-creating property* of these systems [8].

Additional to this internal dynamics, the sustainable development of a system is interdependent with its environment and therefore the considered system has influence on the environment and not only the other way round.

With regard to the innovation system it becomes obvious that in order to develop sustainable innovation we have to deal with an *open system* that cannot sufficiently be investigated based on a reductionist point of view such as a static trait approach as is often used in innovation and creativity research. It is necessary to be aware that these approaches can at best deliver *one tiny piece of the overall puzzle of the elephant*. Since the temporal perspective is not taken into account these investigations do not consider potential influences from the rest of the system or from influences of the environment such as the technological, social, and cultural milieus. Especially when the focus lies on the creation of sustainable innovation and consequently on the creative process a systems perspective becomes necessary. By having a closer look at the individuality of creative processes it shows that those processes are never the same, although we try to replicate a certain process. An example for that would be a creativity workshop for product development within a department of the same company for various subgroups of the department itself with the following peculiarities:

- The involved people have different value systems, backgrounds and moods, embedded in different social and cultural milieus. Their ways of thinking will never be the same and consequently the application of supporting creativity techniques and other methods will lead to different outcomes.
- Even the same people cannot duplicate the creative process twice.
- There is a given interdependence among the involved people leading to spontaneous and unpredictable synergies. According to the principle of *nonsummativity* the whole system is greater than the sum of its parts [9]. Further, with respect to the notion of *equifinality*, various paths can lead to the same goal [9]. This dynamic group behavior might be supportive but also destructive for the generation of creative ideas as well.
- The impact of environmental influences on the working group might differ with respect to the temporal context.
- The temporal aspect is responsible for changes within the system but also within the environment. This can lead to either marginal or vast differences in the overall development of the system.

Consequently, the complexity of innovation systems and especially sustainable innovation calls for an understanding of the system not only on a micro-level but also on a macro-level.

3.2. Knowledge as a Basis for Innovation

Knowledge seems to be a prerequisite for all kinds of sustainable competitive advantages [10, 11, 12]. As Nonaka et al. already pointed out, knowledge itself is dynamic and therefore cannot be defined based on a traditional epistemological view that defines knowledge as “justified true belief”. Despite this “absolute, static, and nonhuman view of knowledge” they posit that knowledge is context-specific, relational, humanistic, and dynamically created in social interactions, and is of either an explicit or implicit kind. Further, knowledge is distinctive from information. While the second can be considered as a flow of messages, the first is “created by that very flow of information and is anchored in the beliefs and commitment of its holder” and can be defined as “a dynamic human process of justifying personal belief toward the truth” [10].

4. MISINTERPRETATIONS

It is true that scientific endeavor often shows a high tendency to reduce the development of a system to simple predictive equations no matter how complex the system actually is. But *unpredictability* alone is not an appropriate indicator for chaotic systems because that kind of unpredictability has a specific origin: in many instances it is more the difficulty to exactly specify the development of a system because the mechanisms and rules behind it are hard to observe. Therefore, this is not a real random event, but is more an *imprecision of observations* that leads to unpredictability.

Another misunderstanding about chaotic systems is that nonlinear dynamic systems are all chaotic, therefore applying the two expressions synonymously. Instead, *the possibility of chaos is one of the interesting features of this class of systems* [13]. This feature seems to be especially interesting for the innovation process: there might be phases based on periodic working processes such as regular meeting or specific working steps within the project management; additionally the innovation process contains typical creative phases with a more chaotic behavior in which high flexibility, openness, and an *“everything is possible mentality”* dominate. To sum it up, chaotic or nonlinear dynamic systems therefore not only require flexibility, openness, and creativity, but also structured processes based on determinism.

5. INNOVATION AS A NONLINEAR DYNAMIC SYSTEM

With regard to the ongoing changes of the scientific world view Küppers states that traditional, innate views of considerations of space, time, and causality are not suitable to appropriately describe and understand all the phenomena of the natural world. As an example, he further points out the failure of traditional rational views as soon as we touch the world of the smallest and the largest dimensions as a part of complexity [14]. In a similar way Kaye talks about the *failure of reductionism* when complex systems are attempted to investigate; therefore he calls reductionism also *nothingbutism* [15].

The expression chaos has to be used very carefully, since within our society and also within the scientific community chaos is still mainly associated with a negative meaning. In its general use chaos is used to express turmoil, a lack of order, disaster, overwhelming confusion, together with a lack of structure and rules. In fact these systems are very well characterized by order and self-organizing capabilities. Just as chaos theory developed to be a serious scientific field of interest at the end of the 1970s it was increasingly shown that chaos can't be put on a level with exceptional situations such as catastrophes; instead *chaos is a main characteristic of most living systems*. Irregularities, turbulences, feedback loops, interdependencies, nonlinearity, dynamics, and the inability to deterministically forecast future developments were shown to be manifestations of chaos with real-life meaning. Consequently, chaos is becoming more and more a synonym for today's world.

It is by no means necessary that the whole system acts in a nonlinear manner in order to be understood as a nonlinear system, chaotic or near-chaotic system. Rather, nonlinear systems are systems within which at least some relationships of elements or subsystems are nonlinear [13]. Furthermore, not only highly complex systems are capable of discontinuous nonlinear behavior. Instead *relatively simple, mechanistic, completely deterministic systems can be capable of surprising, discontinuous, and seemingly unpredictable change* [13].

If we have a closer look at the special issue of innovation and its characteristics it becomes more obvious that these are nonlinear systems and that they are deterministic-chaotic systems - this seems to be especially true for radical innovation:

- Innovation systems are chaotic they behave within *deterministic rules* [16]: This implies that the system's elements are determinable and the internal and external system relationships are based on well-known rules such as the rules of natural law, although based on the uncertainty principle it is not possible to attain perfect knowledge on the initial system's conditions [21]. With respect to changes in such systems it shows that already *minor changes of the initial state* of the system - such as changes with regard to one single element - *show exponential effects* for the development of the overall system, as a result of nonlinear dynamic system relationships. Because of those nonlinearities the whole is more than the sum of the single elements of the system.
- Innovations and especially sustainable innovations are nonlinear systems with a *complex system's character*: Usually the system's initial state cannot precisely be described because of the huge amount of interacting elements and subsystems. The initial state of the system is mainly determining the further development of every system, but with regard to self-organizing systems those initial conditions are changed themselves by the development process itself [14]. As described, the system's behavior - this can be understood as the mechanisms that make the system work, or alive when we are talking about living systems - shows highly dynamic nonlinear behavior leading to changing patterns and structures as well as intensities over time [17]. As a consequence the target state of the system is unknown or at least ambiguous. The chaotic behavior of systems is very much related to complex systems, but it is crucial to be aware, as Schuldberg states, that such complex systems can be the result of the nonlinear dynamic coupling of relatively simple processes which sometimes also rely on hierarchical rules [13, 18]. In other words, *under certain circumstances an agglomeration of simple systems can show complex behavior*.
- Since at least parts of the innovation system, especially elements of the creative processes, behave nonlinearly, this leads to an inability to describe the effect of a single cause on the overall system based on exactly formulated natural laws but more or less imperfect knowledge of the initial state of the system and [14].
- In contrast to inventions innovation show strongly interdependent dynamic internal and external feedback effects. Single effects might have tremendous and unpredictable effects on the overall innovation system.
- Within innovation processes it is shown that due to these dynamic feedback effects the *initial state itself is continuously changing* [14]. Therefore, a final

state of a system and also the target state of the system cannot be considered as a status quo. Instead, the final and target state of the system becomes itself a starting point for further system developments.

- This chaotic characteristic of a system does not imply that there is no kind of structure and order. We need a systems view that goes beyond by mapping the system's behavior within the phase space of the system in order to make the system's inherent order and pattern apparent. In that way the structure and order becomes visible similar to a radiogram. Hence the system's *phase space* gives a description of the current state of the system, but also where the system is moving next [13, 19, 20].
- The chaotic parts of the innovation system can be chaotic to a different degree. That means that the nonlinear behavior of those systems differs in strength to what can be expressed in the *Ljapunov exponent*. The stronger the nonlinearity the shorter the time available to make - at least rough - forecasts about the system developments. Here, the inability to deterministically predict the future developments in the long run becomes obvious. Firstly, knowledge on the general structure and patterns of the system has to be attained - similar to a road map. Secondly, scenarios of the nonlinear developments of those structures and patterns need to be constructed; the danger at this stage is that deterministically based algorithms of future scenarios are developed based on traditional scientific reductionism. In that way the mistake is made that nonlinear phenomenon are described with linear means. Additionally, the less precise the knowledge about the initial state of the system, the more uncertain such predictions will be. However, no matter how much work is invested to define the initial state of the system, Heisenberg already pointed out within his *uncertainty principle* the impossibility to attain perfect knowledge on the initial conditions of a system; in detail, Heisenberg argued that it is impossible to know both the position and the velocity of an object with absolute certainty [21]. This can also be understood as the fuzzy initial situation of a system. Since uncertainty cannot be avoided totally, the development of such systems cannot be predicted in the long run because sudden minor changes might again have huge effects on the development of the whole system.
- Innovation systems cannot totally rely on Newton's mechanistic understanding of the functioning of the world. Nor can they rely on Laplace's deterministic point of view that considers all processes on the world in all scales (from the smallest to the largest dimensions) as determinable and predictable under the assumption that the appropriate information concerning the initial state of the system can be provided [15].
- Only sustainable innovations are *autopoietic systems* [8, 22, 23] by showing a system behavior that is directed towards a continuous renewal of itself.
- The development of innovation systems is further characterized by *bifurcations* that are changes from one type of system to another, such as from non-chaotic to chaotic [20].
- The system's peculiarities tend to be a cloud of system representations around certain *attractors* [13, 20]. Innovation systems consist of both non-chaotic and chaotic parts and are characterized by a variety of attractors. Attractors can be understood as specific parameter values which cause the system to move toward them and tend to stay there. *Fixed-point attractors, limit-cycle attractors,* and *torus attractors* characterize non-chaotic systems; the *strange attractor* characterizes chaotic systems.
- The *fixed-point attractor* is not moving but fixed to a single position. This form of attractor is typical for a system which tends to a stable, single-valued equilibrium. A typical example for a fixed-point attractor would be a pendulum that tends to go back to a determinable and stable position and which is damped by friction. Systems characterized by this attractor are non-chaotic and stable with regard to the system's initial conditions. An example in the organizational context is a fixation of the companies activities based on one parameter such as profit - based only on the cost-earnings situation - without considering the inherent innovation capabilities of the organization.
- The *limit-cycle attractor* moves along an ellipse, called a limit-cycle. Every combination of time and space will be reached again after a specific cycle duration. The pendulum of a grandfather's clock is such an example. In contrast to the pendulum describing the fixed-point attractor, the energy taken away from the system because of friction is added in each swing of the pendulum. Also these systems are non-chaotic although they are more complex than the systems characterized by a fixed-point attractor. A continuous product development program can be an example for a fixed-cycle attractor within an organization: the development of a new car is followed by the phase of introduction to the market, followed by the phase of market expansion, which is again followed by the phase of product development and so on.
- An even more complicated attractor than the limit-cycle attractor is the *torus attractor*. The movement of the attractor can no longer be described within two dimensions of the phase-space.

Due to the inclusion of the third dimension the phase-space forms a torus. An example for this attractor are the oscillations of three independently swinging grandfather's clock pendulums. This attractor system is also non-chaotic, although more complicated than systems characterized by the fixed-point attractor or the limit-cycle attractor. Nevertheless its movement can still be predicted. Within an organization an example for this is the increasingly complicated interaction between diverse parameters of the R&D program: the volume of the R&D budget influences the number of R&D projects which further influences the number of innovative products developed; this again influences the market success of the organization which influences the volume of the R&D budget made available and so on.

- Chaotic systems are characterized by *strange attractors*. These are *regions containing bounded but ever-changing (never-crossing) trajectories in phase space* [13]. Strange attractors behave differently compared to the other attractors since the system's characteristics can be understood as confined trajectories whereas the system does not show stable behavior as is the case with systems that are characterized by regular attractors [13, 19]. The system's parameter values are approaching the strange attractor, but always at totally different phase-space positions. Therefore, predictions in the long run are just not possible. An example on the organizational level would be the potential success of a radical innovation introduced onto the market or the potential success of a start-up of a new company. In both cases the dynamic interdependencies within the organizational system itself and also between the organization and its environment may be responsible for tremendous changes of the whole investigated system caused by slight changes of the initial system's conditions. Certainly these systems show order and patterns, but they cannot be predicted in the long run.

6. SYSTEMS APPROACHES TO CREATIVITY

Going now a step further, what are the implications of chaos theory and systems thinking on creativity as the core factor of successful innovation? Almost all scientific work in the field of creativity is focused on creative personalities and relies on a static trait approach. Nevertheless, although there has been as yet just very little endeavor on chaos-theoretical considerations in creativity research - exemptions are Schuldberg [13] and marginally few other authors such as Richards [24], and Skarda and Freeman [25] - there is a selection of scientific representatives who applied a systems thinking approach within their research:

- The evolving systems approach as introduced by *Gruber* focuses on the unique creative person at work and is both a theory and a method. Within this approach the creative person is seen as an interrelated system of knowledge, purpose, and effect [26].
- Within his model of creativity *Gardner* builds up a system consisting of three interdependent processes involving the individual, the discipline, and the judgmental society [27].
- In *Csikszentmihalyi*'s systems view creativity is seen as the intersection at which individuals, domains, and fields interact [28]. Within this model the domain stands for the cultural aspects and the field for the social aspects. In that way the influence of the environment on the operating individual is taken into account.
- The systems model of *Ford and Gioia* mainly focuses on the organizational level of creativity [29]: On an individual level creativity is expressed as the interaction of understanding, motivation, together with knowledge and ability. Based on the idea of Csikszentmihalyi, Ford and Gioia similarly consider the individual's creativity in the context of the domain's rules and instructions. The creative action stands for diverse variations which are presented to the members of a field. The field selects are chosen according to the prevailing value system. The domain then communicates and legitimates those selected creative thoughts and actions again towards the individual.
- Further requiring mention is also the systems model of *Amabile*. Within her componential model of creativity she focuses especially on the influence of the social environment by taking into account the impact of task motivation, domain-relevant skills, and creativity-relevant skills [30].
- Another relatively new approach is the dynamic systems model of creative problem-solving by *Steiner*. Here, in this metaphorically labelled Planetary Model, creative solutions and ideas are generated based on the dynamically interacting sub-processes of problem finding, objective finding, stakeholder management, and the generation of alternatives. These sub-processes are specifically problem-focused activities and are themselves embedded and interacting with the appropriate thinking styles, competences, and innovation climate. All components of the system of creative problem-solving are strongly interdependent so that stakeholder-related peculiarities and environmental influences in particular are considered. This also leads to permanently changing patterns of the

system in which circularity instead of linearity becomes the determining characteristic [31].

7. IMPLICATIONS FOR CREATIVE COLLOBORATION

By taking into account the peculiarities of innovation systems and their patterns of development, the question to answer is how to deal with such nonlinear dynamic processes? Further, what connection can be identified between nonlinearity and chaotic systems and creativity in detail? A core answer already lies in the described characteristics of nonlinear dynamic systems: dynamic nonlinearity provides the flexibility and variety needed for being highly creative, but the whole system is not necessarily nonlinear. Since within nonlinear dynamic systems only one relationship among the system's components is enough to lead to nonlinear dynamic system behavior [13], the non-chaotic system's patterns that follow relatively simple and often hierarchical rules have to be considered as well. In other words, nonlinear dynamic systems such as the development of innovations needs both, creativity and structure, but applied accurately according to the given system's peculiarities of the overall system and its sub-systems. In other words, creative performance usually requires more than just structured working processes. Actually, creativity on an individual, organizational, or even inter-organizational level requires conditions that give space for flexible, spontaneous, and transboundary thinking and acting. By that, chaotic systems provide needed prerequisites for the creative evolvement of individuals and groups as long as the degree of nonlinearity expressed by the Ljapunov exponent is not so high that it becomes counter-productive or distructive for the creative performance. Here, no single one optimal degree exists for specific processes. Because of the interconnectness of the single components of the system together with the interplay with the system's environment, no general indicators or rules can be found or applied. Therefore, the affiliated challenge is to set up pre-conditions suitable to the given system's conditions, including the peculiarities of the involved creative actors. In a system where chaos and creativity are strongly tied to each other the *question is about how much planning versus how much chaos is useful for creative performances under specific conditions of the system and the relevant environment*.

8. CONCLUSION

This paper attempted to point out how most real-life systems on different scales are interconnected. Consequently, a single action taken on a small scale might have tremendous influence on a large scale system in the long run, although the dependency might not be obvious in the first view. With respect to the problem-solving agents and stakeholders it also shows that one has to be aware of the high degree of responsibility for larger scale systems, although the system one is working on seems to be incremental. In order to understand the underlying mechanisms, nonlinear dynamic systems theory might provide for a fruitful contribution. By taking into account these implications it becomes more probably that more sustainable forms of innovation can be generated and positive synergies on different scales arise.

Nevertheless, the question is what serious contribution chaos theory as the theory on nonlinear dynamic systems can provide for the generation of innovation and creative problem-solving processes in general? First of all, chaos theory as a field of systems science is able to scientifically deal with such fields of interest to provide for a broader understanding of such phenomena contrary to the focused view of traditional reductionism. Therefore, the better understanding of innovation and creativity might help to enhance the knowledge base of science and application [8]. Further, group behavior would be another interesting field for further application of chaos theory and especially for the development of appropriate computer-supported mathematical models. An example for a logical application is the implementation and diffusion of an innovation into the market with effects on the various groups of customers from innovators, early adopters, early majority, late majority, and laggards as well as resisters [32]. In that way nonlinear dynamic systems theory can provide for an additional scientific perspective with practical implications as well.

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