AN INNOVATION THROUGH A COMPLEXITY LENS

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Summary: There is a common view that successful innovation ad innovativeness are among critical factors determining business success. Crucial for long-term survival is the ability to innovate in both steady-state and turbulent conditions. Seeing organizations through a complexity lens reveals that the ability to double-loop learning and complexity acceptance are the most critical factors influencing organizational innovativeness in unstable states.

Keywords: complexity science, managing for innovation, complexity acceptance.

1. Introduction

It is easy to notice that in the last decade "innovation" has become the "magic word" in management, organizational, political and economic studies and praxis [1, 2]. There is a common view that successful innovation ad innovativeness are among critical factors determining business success. Despite widespread awareness of the "innovation imperative", many policy- and decision-makers have narrow view of innovation considering it mostly as a source of product/technological outcomes [3]. Many organizations fail to overcome problems posed by exploitation-exploration paradox [4]. Common misconception is, according to E. Fitzgerald, A. Wankerl and C. Schramm, seeing innovation process in an oversimplified linear way: discovery → invention → development → product → market → profit. Although this linear model "may have some validity" as ex-post recording, "the trouble is that strains of inaccurate linear thinking persist, and they prevent us from understanding how to innovate more effectively" [2; p. 16].

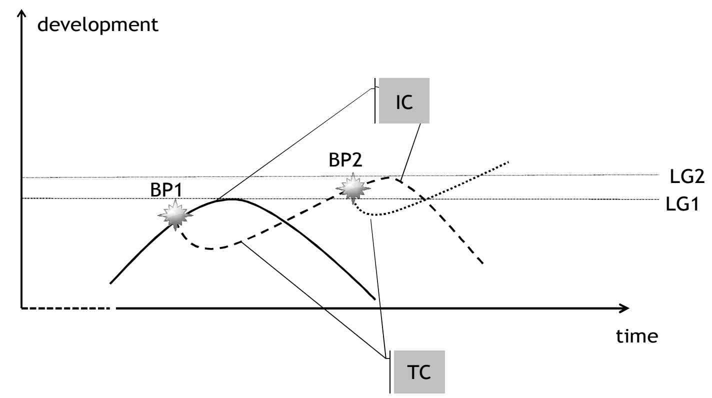
Mental models or sense-making of innovation are important factors in the success of facilitating innovation. Too narrow /too static view of innovation could hamper innovative potential and limit the benefits of individual innovativeness. There are holistic and systemic perspectives that could help overcome these barriers. This paper, that focus on one of them, attempts to describe benefits of applying 'complexity lens' to the study and understanding innovation issues and connected with them managerial problems.

2. Complexity science

The word "complexity" originates from the Latin *complexus* (wholeness) [5]. Complexity science address these issues regarding natural and social systems that cannot be satisfactorily studied using reductionist approaches. Complexity science is rooted in the physical sciences (physics, biology, chemistry) and systems theories. It consists of collection of approaches among which the most influential are: dissipative structures theory [6], complex adaptive systems theory [7, 8], *autopoiesis* theory [9].

Complex systems are omnipresent. Classic examples of complex systems include biological cells, ecosystems, social systems, living organisms, the Internet. The most important (and mutually linked) properties of complex systems are as follows: [10-15]:

Nonlinearity. Nonlinearity of complex systems refers to the existence of cause-effect feedback loops. The nature of this feedback can be reinforcing (positive, amplifying) or balancing (negative, stabilizing). Feedback loops interact with each other causing nonlinearity of system behaviour; "small" causes can have "big" results and vice versa. Feedback is critical element of complex system [13, 16]. The nonlinear behaviour triggered by feedback is history-dependent. In consequence, past of complex systems is "co-responsible for their present behaviour" [17; p. 13].



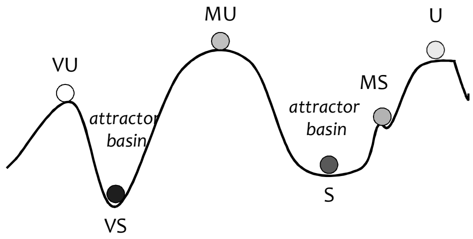
BP1,2 – bifurcation points; TC – transformative changes
IC – incremental changes; LG1,2 – limits to growth

Fig. 1. Transformative and incremental changes
Based on: [18; pp. 432-434]

Evolutionary potential. System's capacity to evolve depends on its stability. System behaviour can take on various forms. In the stable states systems follow attractors. F.M. van Eijnatten defines an attractor as "a force or condition that draws a … system to repeat a typical pattern of behaviour (…) Although not acting as an external force, the attractor still serves as a sort of magnet." [18; p. 433]. An attractor could be a point (when system is in a state of equilibrium) or cyclical pattern. Consequently, stable systems display low adaptability and evolutability [8, 19]. In the unstable states systems do not demonstrate any fixed, repeatable patterns of dynamics. They "cannot maintain their behaviours, as small forces can result in systems disruption" [19; p. 355]. The highest capacity for evolving is at the edge of chaos (in "the zone of fruitful turbulence" [20; p.154]). E. McMillan offers vivid visualization of this concept: "It is (…) like a vibrant planetary sea that is influenced by the gravitational forces of two large planetary neighbours. One is the planet of Far from Equilibrium where all is utter confusion and disorder. The other is the planet of Equilibrium where the order is so complete that nothing disturbs it. It is a lifeless planet." [14; p. 94]. Complex system, operating at the edge of chaos (far from steady states but not in the unstable states zone) follow so called strange attractors. "When set in a strange attractor, there may be a number of zones of activity that the system regularly visits, providing a broad set of constraints on overall behaviour but allowing the system to move between activity zones as the system develops" [21; p. 413]. Evolution of complex systems is a result of internal and external interactions. There are two modes of change undergoing by dynamical systems

[22]. The first type of changes are incremental in nature and occur in the attractor basin (i.e. “the region in which the attractor is successfully able to execute its magnet function” [18; p. 433]). The second type is “a transformative change” [18] or “an interattractor change” [22] typically referred to as bifurcation (Fig. 1). After reaching the bifurcation point, system is influenced by others attractors. According to F.M. van Eijnatten system development may be characterized as “a dynamical process passing from one attractor basin to the next in an incessant journey toward the ‘edge’ of chaos” [18; p. 434]. During this journey system travels across attractor landscape (Figure 2). Whereas in a stable state system (in Figure 2 visualised as a ball) is captured in its attractor basin and needs very strong perturbation to leave this basin, in an unstable state interattractor change may be caused by really weak impulse.

Self-organization. Complex systems can reconfigure their internal connections and activities. Although this process is internal, it may be caused by changes both internal and external to the system (changes in its environment). To selforganize system needs to be open (“by being open they can exchange matter and energy and so stay alive and far from equilibrium” [14, p. 29]) and maintain connectivity (“connections, especially dense, rich connections, transmit information and enable meaning creation among subunits, thus providing systems with improved capacity to learn” [15, p. 192]). Classic examples of self-organization in natural world are herd behaviour, hurricanes, living cells.



VS – very stable state; S – stable state; MS – moderately stable state; MU – moderately unstable state; U – unstable state; VU – very unstable state

Fig. 2. Attractor landscape
Based on: [18, p. 435; 23, p. 199]

Emergence. Complex systems exhibit emergent properties. Considering emergence it is useful to assume two levels of system description; the microscopic level and the macroscopic one. Emergent properties are observable on the macro-level, but they neither exist on, nor could be deduced from the micro level**.** A classic example of emergence is so called „swarm intelligence”- typical for social insects (a swarm behaviour – macroscopic level; a single insect – microscopic level). Another example of emergence, given by Fritjof Capra [24, p. 41], is a sweet taste of sugar (macroscopic level) that “resides neither in the C, nor in the O, nor in the H” (microscopic level). Self-organization is usually accompanied by emergence, but not always: “Self-organization exists without emergence, and emergence exists without self-organization” [16, p. 187].

Complex systems should be distinguished from complicated ones. The latter usually contain numerous connected elements and these have many attributes. However, as long as this numerosity of elements and connections are stable, system is not complex. Good examples of complicated system are mechanical clock [25] or jumbo jet [26]. Both of them are decomposable and predicable (i.e. produce controllable cause-effect relationship). It is possible “to understand, to model, and to reproduce complicated systems by dismantling the system to its constituent elements, known as reductionism” [25, p. 456]. Complex systems are not sums of their parts; they evolve and their elements’ rules emerge; because of emergent properties and nonlinear dynamics, behaviour of whole system cannot be predicted from its components' behaviours. Therefore "it is of limited use to analyse complex systems by the traditional 'reductionist' methods of the natural sciences, since these assume that full knowledge of the parts gives full knowledge of the whole." [27, p. 49].

Human social systems (i.e. organizations) can be understood as complex or merely complicated systems. Advocates of the former approach adapt various complexity science theories to study organizations; dissipative structures theory [28, 29], *autopoiesis* theory [30, 31, 32] and complex adaptive systems (CAS) theory. The last one, as the most frequently applied in the organizational context [33], will be presented below.

A complex adaptive systems can be defined as open evolutionary aggregates of interacting agents [34]. Agents (basic components of CAS) interact simultaneously by sending and receiving signals, take actions according to received signals and their schemata [7]. A schema is "set of rules that reflects regularities in experience and enables a system to determine the nature of further experience and make sense of it" [35, p. 289]. Agents can have multiple competing and evolving schemata. The key properties of CAS are heterogeneity and diversity (of agents; their schemata, their behaviour), adaptability, coevolution and agency – "the ability to intervene meaningfully in the course of events" [36, p. 391]. Agency is an unique property of CAS. Non-living complex systems lack agency; for example in water neither oxygen nor hydrogen have ability to respond actively to events and to learn from their experiences [8]. Adaptability of CASs manifests itself in their ability to learn and adapt to new conditions. This learning and adaptations are mutual with system's environment. In other words, CAS and its environment coevolve; system adapts to its environment that is adapting to system's responses. "Coevolution means that there are changes in the underlying elements of the system, i.e. systems gradually shed elements or connections of the system that may have been useful in the past, and they adopt new elements and patterns of interrelationships that may be useful in the future. Thus, self-organizing can be triggered by an external event, but the self-organizing itself creates a change in the system to which the environment then reacts, and a continuing cycle of mutual learning and adaptation occurs" [15, p. 192]. In a CAS self-organization is accompanied by emergence [16, 25].

The most interesting type of CAS is complex adaptive *human* system. Human agents are cognitive, self-aware, exhibit reflexive behaviour and have linguistic capability [37]. They not only react to emergent global phenomena (downward causation) but also can try to consciously impact them. This feature of complex adaptive human systems is called *second-order emergence* [38, 39]. According to N. Gilbert "second order emergence occurs when the agents recognize emergent phenomena, such as societies, clubs, formal organizations, institutions, localities and so on where the fact that you are a member or a non-member, changes the rules of interaction between you and other agents" [38, p. 6]. In this respect, modelling human complex systems is by no means easy.

In organizational context CAS theory principles could be applied on various levels and in various way. M. Tilebein [40, pp. 1095-1096] distinguishes four levels of observation:

1. Individual level (emergence of knowledge, culture or meaning).
2. Organizational sub-unit level (emergence of knowledge, of innovation, communication structures).
3. Firm level (emergence of knowledge, of innovation, of communication structures, of strategies; production processes, org. structure, information processing).
4. Network or industry level (emergence of knowledge, of innovation, of communication structures, interorganizational production, supply chain management, value networks).

As for ways of implementation, we can roughly distinguish two main approaches [41]:

- the “hard approach” – simulation modelling (agent-based simulations) [42, 43],
- the “soft approach” that includes inter alia *complexity thinking* (i.e. looking at /thinking of organizations with acceptance of their complexity) [18, 44], using *complexity metaphors* [28] and *narrative modelling* [45].

Proponents of these approaches criticize each other. K. Richardson [13] names agent-based simulations “the neo-reductionist school” of complexity because of unavoidable reductionism in agents’ rules modelling. Other researches maintain that metaphorical and analogical applications are superficial and “vulnerable to faddism” [46, p. 19] and only “moving beyond metaphor” [47] rigorous operationalizations can make complexity science useful in organization studies. However, metaphors in organizational life should not be undervalued. As G. Morgan stated: “By using different metaphors to understand the complex and paradoxical character of organizational life, we are able to manage and design organizations in ways that we may not have thought possible before.” [48, pp.12–13]. In organizational context metaphors are considered by many as the best use of complexity science [49].

3. Innovation and managing for innovation

Innovation can be understood as a process and as an outcome. According to M.M. Crossan & M. Apaydin’s broad definition, innovation is “production or adoption, assimilation, and exploitation of a value-added novelty in economic and social spheres; renewal and enlargement of products, services, and markets; development of new methods of production; and establishment of new management systems” [4, p. 1155].

Concepts related to innovation include:

- individual innovativeness understood as “developing, adopting or implementing an innovation” [50, as cited in 51, p. 2],
- organizational innovativeness,
- entrepreneurship - related to innovation as “both involve the processes of discovery, evaluation, and exploitation of opportunities (entrepreneurship) and novelties (innovation)” [4, p. 1177],
- creativity regarded as a crucial prerequisite for innovation [52].

The most relevant questions in innovation related issues seems to be: *How innovation occurs?* and *Are innovation processes manageable?* E Fitzgerald, A. Wankerl and C. Schramm [2] point out that innovation process is “messy” and linear concept of innovation as the chain *discovery → invention → development → product → market → profit* is misleading. Innovation is a heterogeneous process that includes multiplicity of decisions and depends on many social, psychological and another “human” factors. As A. Styhre put it: “ innovation must be further problematized as what is partially dependent on formal resources such as skills, technology, management practice, communication, etc. (i.e., endogenous factors), partially the outcome of exogenous factors such as serendipity, luck and chance” [53, p. 137].

As for the second questions, M. McElroy argues that while corporate business institutions with centralized planning and control schemes are only century old, “human social systems – indeed humanity itself – have been producing new knowledge at impressive rates for millennia now” [54, p. 148]. Therefore more adequate term than “managing innovation” is “managing for innovation.”

One of the most challenging and important problems in managing for innovation is compromising short-term survival goals with long-survival ones [40, 55, 56]. Fundamental for the first type of goals are *incremental innovations* (also known as *evolutionary, continuous, steady-state, exploitative innovations* [56, 57, 58]); for the second one - *radical innovations* (*revolutionary, disruptive, discontinuous, breakthrough* or *exploratory innovations*). This dilemma is known as the exploitation-exploration tension or efficiency-flexibility tension: “Exploitation hones and extends current knowledge, seeking greater efficiency and improvements to enable incremental innovation. Exploration, on the other hand, entails the development of new knowledge, experimenting to foster the variation and novelty needed for more radical innovation” [58, p. 696]. Ability to balancing conflicting goals of efficiency and innovation is called organizational ambidexterity. “Ambidextrous firms are capable of simultaneous, yet contradictory, knowledge management processes, exploiting current competencies and exploring new domains with equal dexterity” [58, p. 696]. In another words, ambidextrous organizations are capable of competing with two business models at the same time or “to play two games at once” [59], which is difficult to handle. As M. Magnusson, P. Boccardelli, and S. Börjesson note: “the tools and methods used to search for, select and implement steady-state innovations may act as obstacles to radical and discontinuous innovations” [56, p. 2].

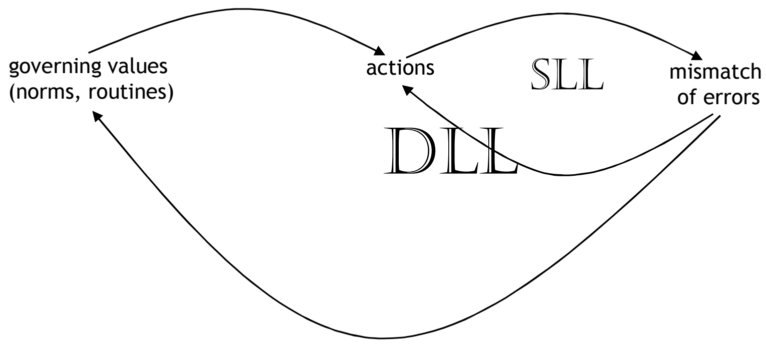


Fig. 3. Single-loop (SLL) and double-loop (DLL) learning
Adapted from: [63, p. 256]

Whereas continuous innovations base on ‘do better’ approach, discontinuous innovation needs revolutionary change (‘do different’ approach) [57, 60]. This corresponds to the single-loop learning (incremental learning, adaptive learning,) – double-loop learning (transformational learning, generative learning) distinction [61, 62, 5] presented in Fig. 3.

Single-loop learning leads to elimination of errors in performance without changing the governing norms and values (the classic example of single-loop learning is thermostat adjusting the object’s temperature to the demand level [61]). In double-loop learning discrepancies between expected and actual effects lead to questioning the underlying norms (continuing the former example: “a thermostat that could ask, ‘Why am I set at 68 degrees?’ and then explore whether or not some other temperature might more economically achieve the goal of heating the room would be engaging in double-loop learning” [61, p. 99]).

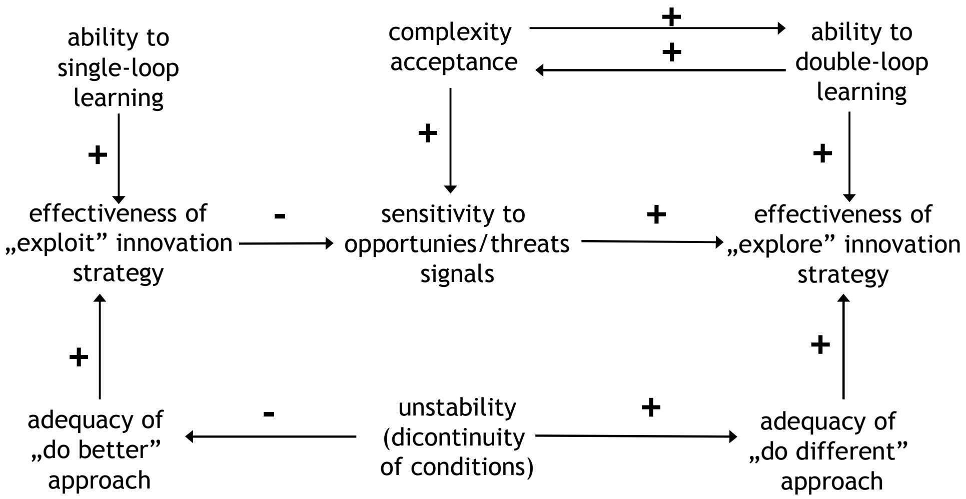
Neither “do better” nor “do different” approach (resp. “exploit” and “explore” innovation strategy) is absolutely effective or ineffective. According to J. Bessant et al, “the question is one of appropriateness to external conditions for innovation. In simple terms one reason why existing players do badly when discontinuous conditions emerge is that there is a mismatch between their dominant steady state archetype and the very different requirements for discontinuous innovation." [57, p. 1373]. Applying complexity vocabulary, in the attractor basin (Fig. 2) incremental innovations could be effective, whereas in unstable states – not. It is important to note, that "topography" of attractor landscape is dynamic; systems not only travel across landscape, but also shape its peaks and valleys. F.M. van Eijnatten offers here the "co-jumping on a trampoline" metaphor: "The game players continuously influence each other's positions in terms of local minima and maxima. With other game players jumping on the same flexible surface it becomes highly unpredictable whether or not you will ever succeed in your highly desired frog-leaped mega-jump. It will depend on the kinds of interaction patterns or rhythms that accidentally develop" [18, p. 435]. This illustrates also coevolution of complex systems; organizations coevolve with their environments; apart from reacting to environmental change organizations could make environment ("another players") react to changes initiated by them. Nevertheless, as J. Bessant et al state, "the real challenge is in building the capability within the firm so that it is prepared for, able to pick up on and proactively deal with innovation opportunities and threats created by emerging discontinuous conditions. In other words, to develop alternative routines for discontinuous innovation ('do different' routines) which can sit alongside those for steady state 'do better' innovation" [57, p. 1368]. Typical sources of discontinuity and problems posed by them are listed in Table 1. "Established players" may be more vulnerable to many of these problems, than new entrants that do not have successful "exploit" innovation strategy.

Tab. 1. Sources of discontinuity and problems posed by them

Sources	**Problems**
New market emerges	Established players don't see it because they are focused on their existing markets
New technology emerges	Don't see it because beyond the periphery of technology search environment
New political rules emerge	Established firms fail to understand or learn new rules
Running out of road	Current system is built around a particular trajectory and embedded in a steady-state set of innovation routines which militate against widespread search or risk taking experiments
Sea change in market sentiment or behaviour	Don't pick up on it or persist in alternative explanations (cognitive dissonance)
Deregulation/shifts in regulatory regime	Old mindsets persist and existing player is unable to move fast enough or see new opportunities opened up
Unthinkable events	New rules may disempower existing players or render competencies unnecessary
Business model innovation	New entrants see opportunity to deliver product/service via new business model - existing players have at best to be fast followers
Shifts in 'techno-economic paradigm'	Existing players tend to reinforce their commitment to old model

Chosen from: [57, pp. 1369-1370]

Figure 4 presents crucial factors influencing effectiveness of both “exploit” and “explore” innovation strategies. Under stable conditions effectiveness of “exploit” innovation strategy depends mostly on the ability to incremental learning. R. Chiva, A. Grandío, and A. Alegre observe that whereas “organizations and people are becoming good at single loop learning (…) practitioners and organizations are not normally so adept at second loop learning, at changing their theories, models or paradigms.” [5, p. 115]. The core of the exploitation-exploration dilemma seems to be sensitivity to opportunities/threats signals blunted by successful “exploit” strategy. The factor that could compensate this negative influence is complexity acceptance. That makes the ability to double-loop learning and complexity acceptance the most critical factors influencing organizational innovativeness.



A —+→ B positive cause—effect relation (if A increases/decreases then B increases/decreases)

A —−→ B negative cause—effect relation (if A increases/decreases then B decreases/increases)

Fig. 4. Crucial factors influencing effectiveness of innovation strategies. Casual loop diagram

Organizations facing internal and environmental complexity can choose one of two policies: complexity reduction or complexity absorption [15, 64]. According to D.P. Ashmos et al., choosing the first alternative results in strategies that maximize rules and minimize connectivity among agents. Minimizing connections involves separation of human agents, minimization of their participation in decision processes, relying on elaborate control mechanisms and detailed standardization procedures. In this way “the organization tries to simplify and reduce the amount of data and the number of choices available to its members. Sensemaking is undertaken by only a few agents whose roles place them at the top of the hierarchy (…). This is seen as a way of achieving apparent order in a seemingly complex and disorderly world” [15, p. 193]. As a result organization become non-adaptive. Choosing the second alternative (complexity absorption) an organization, instead of creating complex rules to simplify processes, uses simple rules that could produce complex processes. That is vital for the most important CAS properties is enhancing connectivity by maximizing participation [15].

Agents' heterogeneity, autonomy and learning capabilities are crucial for complex systems' viability. Learning is the main force for supporting connectivity, self-organization and evolution of complex adaptive systems [5, 33, 65]. "The more knowledge flows, knowledge sharing and learning between different organizational parts and external agents there are, the more opportunities there are for knowledge generation and new combinations" [66, p. 450]. In complex adaptive system learning occurs when diverse agents influence and affect each other. Therefore in complex human adaptive systems diversity of actors and their schemata is needed and should be encouraged.

In the complex adaptive system theory view, management does not mean handling organizations with command and control, but "influencing the process of change of a complex, adaptive system from one state to another" [16, p. 188]. Managerial leading should be indirect, focused on creating conditions for effective interaction, communication and learning [20, 67, 68, 69]. As B. Regine and R. Lewin put it: "Leading in a dynamic system is more like an improvisational dance with the system rather than a mechanistic imperative of doing things to the system, as if it were an object that could be fixed" [68, p. 17].

Because in complex systems agents cannot predict and consequently plan long-term future, strategies should evolve along with the system's and its environment's evolution [67, 69]. "Strategy has become a trial-and-error process, evolving through the discovery of what works. As a result planning cycles are shorter, and because quick responses are required, tactics often dictate strategy." [67, p. 15].

As in complex systems "effectiveness and efficiency are assumed to require an optimal balance between creative activities (exploring new opportunities) and productive activities (exploiting current capabilities" [70, p. 740] evaluation methods and incentive systems should mirror this trade-off between innovation and efficiency [40, 57].

4. Conclusions

Providing organizations do not operate in stable environment, crucial for long-term survival is the ability to innovate in both steady-state and turbulent conditions. Today, fast moving markets, communication technologies, globalisation and its consequences remind us that constant change in socio-economic systems is obvious. Essential for long-term survival became ability to sense signals of threats and opportunities and proactively initiate change. The main enablers for discontinuous innovation are ability to double-loop learning connected with it complexity acceptance. Although management practitioners hardly ever assume stability of business environment straightforwardly, they often choose to copy with complexity and reduce it instead of complexity acceptance and absorption.

Complexity science does not offer "ready-to-use" prescriptions for success in a turbulent business environment. Nevertheless "complexity lens" could help understand and accept features of complex systems in organizations, follow complexity thinking guidelines (especially the importance of diversity, interactions, communication and learning) and successfully incorporate them into management for innovation praxis.

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