## 1 Introduction

The average life expectancy of the top 500 US corporations by total revenue is between 40 and 50 years, far shorter than that of the average human being (Markovitch, O'Connor, & Harper, 2017). Less than 0.1 per cent actually make it to celebrate their 40th anniversary (O'Reilly, Harreld, & Tushman, 2009). Part of the problem is that of large, established companies fail to adapt and found themselves with reduced capacity to cope with highly uncertain domains (Sainio, Ritala, & Hurmelinna-Laukkanen, 2012; O'Connor & Rice, 2013).

Innovation is critical to the long-term survival of many of today's firms. Incremental innovation can keep organizations competitive with current product platforms, but only radical innovations (RI) can rewrite the rules of the game (Tidd, Bessant, & Pavitt, 2005; Teece, Peteraf, & Leih, 2016). As defined by O'Connor and Rice (2013), RI refers to a product, process, or service with either unprecedented performance features or with such dramatic changes in familiar features or cost that new application domains become possible. Whereas incremental innovation projects are consistent with mechanistic models characterized by linearity and rigid, pre-defined sequence of activities and decision criteria, RI require more organic models to cope with higher levels of technical, market, organizational, and resource uncertainties (Leifer et al., 2000; O'Connor et al., 2008; O'Connor & Rice, 2013).

In this context, innovation scholars have increasingly turned their attention towards the potential of complexity sciences as a way of dealing with uncertainty in projects and capturing influence of context, interaction, and adaptation in an innovation process (Garud, Gehman, & Kumaraswamy, 2011; Bakhshi, Ireland, & Gorod, 2016; Poutanen, Soliman, & Ståhle, 2016). In the same vein, practitioners have been developing strategies to facilitate learning about complexity, such as group sense-making sessions and group discussion boards (Webb, Lettice, & Lemon, 2006; Bäcklander, 2019). Complexity sciences offer concepts, models, and approaches for studying complex systems, i.e., systems that can be understood as a web of many kinds of agents interacting in non-linear, adaptive ways and exhibiting collectively emergent patterns of behavior (Mitchell, 2009; Byrne & Callaghan, 2014).

Although developed in the natural sciences, it is widely recognized that complexity research findings have managerial implications in the organizational sphere (Anderson, 1999; Anderson, Meyer, Eisenhardt, Carley, & Pettigrew, 1999; Mitchell, 2009; Byrne & Callaghan, 2014). In innovation literature, complexity-based approaches have been applied in different contexts, for instance: to provide new insights for achieving balance between short-term exploitation and long-term exploration (Uhl-Bien & Arena, 2018); for engaging sustainable innovation in firms (Iñigo & Albareda, 2016); for developing a framework to new product development (McCarthy, Tsinopoulos, Allen, & Rose-Anderssen, 2006) and a multilevel approach to analyze the innovation process (Dias, Pedrozo, & Silva, 2014), and many others.

According to O'Connor and Rice (2013), in spite of all that has been written about managing uncertainty in innovation projects during the past two decades, firms continue to struggle with the discovery, development, and commercialization of RI. The growing interest of researchers and practitioners in complexity sciences (Webb et al., 2006; Garud et al., 2011; Bakhshi et al., 2016; Poutanen et al., 2016) along with the need for companies to deal with highly uncertain situations indicates both an opportunity and a need to better understand how to develop RIs (Leifer et al., 2000; O'Connor & Rice, 2013). The aim of this paper is to analyze complexity-based models present in the innovation literature and discuss in an integrated way their contributions to dealing with RI.

## 2 Theoretical background

### 2.1 Complexity sciences in innovation studies

Since the open-systems view of organizations began to diffuse in the 1960s, complexity has been a central construct in the vocabulary of organization scientists. The hallmark of the complexity perspective in organizational studies is the notion that at any level of analysis, order is an emergent property of individual interactions at a lower level of aggregation (Anderson, 1999). Complexity sciences encourage researchers to look at the evolution of people interacting with elements in their environments (Byrne & Callaghan, 2014). Rather than use a set of independent variables to explain variation in one or more dependent variables, complexity research asks how the interaction between agents produce different aggregate outcomes (Webb et al., 2006; Uhl-Bien & Arena, 2018). Such a perspective can be highly relevant to innovation research, since innovation often grows out of the interaction of people, technology, and knowledge (Fleming, 2001; Poutanen et al., 2016).

The innovation literature presents various complexity applications. For instance, Mendes et al. (2016) proposed that learning and innovation can be better achieved in organizations if leadership embraces a complex view as an alternative to centralized forms of influence and control. Another example is Dougherty (2017) that proposed a framework of organizing complex innovation systems that capture their emergent, situated, and integral nature. Recent studies provided comprehensive reviews on the topic, relating complexity with networks, knowledge management, leadership, ambidexterity, product design, etc. (Poutanen et al., 2016; Silva & Guerrini, 2018).

Recurrently, RI contexts have been portrayed as chaotic (Leifer et al., 2000) and turbulent (McDermott & O'Connor, 2002). Rose-Anderssen et al. (2005) remarked that the usefulness of complexity sciences to the understanding of innovation activities relies on the evolutionary and creative processes with unpredictable outcomes that characterize it, primarily in RI contexts.

From the complexity standpoint, organizations are dynamical, complex systems comprised of agents (i.e., people, groups, organizations, objects, concepts) who experiment, explore, self-organize, learn and adapt (in varying degrees) to changes in their environments. People as individual complex systems are adept at self-organizing; at manipulating their environments; at turning things to their own advantage; but most of all at learning and adaptation (Uhl-Bien & Arena, 2018; Bäcklander, 2019).

### 2.2 Linking the principles of complexity to the challenges of RI

The principles of complexity stated by Edgar Morin (Morin, 2010, 2015, 2016a, 2016b) can be used to develop complexity-based approaches. Morin's works are recognized as one of the most influential on complexity literature (Castellani, 2018). It is attributed to Morin the development of the philosophy of complexity, encompassing all the pillars of the complexity sciences. The principles of complexity are: C1 – Systemic; C2 – Hologramatic; C3 – Recursive circle; C4 – Retroactive circle; C5 – Reintroduction of knowledge in all knowledge; C6 – Self-eco-re-organization; C7 – Dialogical.

The basic idea in the systemic principle (C1), that comes from Bertalanffy's (2015) General System Theory, is that of opposition to reductionism: the whole is more than the sum of the parts. It means that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole. The organization of a whole produces new qualities or properties in relation to the parts considered in isolation, what is called emergences or emergent behaviors (Morin & Le Moigne, 1999; Morin, 2010). It can be considered that innovation process is about interactions, relationship formation, and knowledge creation among different agents. In this view, as pointed out by Dias et al. (2014), the fundamental question is how innovation emerges out of the interactions of the multiple different players (e.g. individual, department, hub) at multiple different stages.

In addition to the idea that "the whole is more than the sum of the parts", Morin (2016) explained that an organization is not always able to enhance the quality of its components, and therefore the system may be smaller than the sum of the parts. For instance, the idea evangelist (Hansen & Birkinshaw, 2007) may mobilize the entire firm through their deep, high-touch personal networks to increase awareness among employees and persuade them to adopt a new product or business concept; their relationships must span many different parts of the organization for companywide and cross-company diffusion to ensue (the whole is more than the sum of the parts). Conversely, the imposition of norms, procedures, and organizational culture may prune components qualities (system may be smaller than the sum of the parts).

The hologramatic principle (C2) is based on the notion of the hologram in which each point contains almost all the information of the object it represents (Morin & Le Moigne, 1999). Morin (2015) explained that the idea of the hologram goes beyond reductionism (which only sees the parts) and holism (which only sees the whole). It introduces the notion of self-production, in which the products and effects are themselves the producers and cause of what they produce (Morin & Le Moigne, 1999). In an organizational context, it is noticed that the individuals form the firm and the firm is present in each individual through language, culture and norms. This can be related to the recursive circle principle (C3). A firm is produced by interactions between individuals, but the firm, once produced, retroacts on individuals and produces them. That is, individuals produce the firm that produces the individuals; both are products and producers.

Closely related to C3 is the retroactive principle (C4) and the reintroduction of knowledge in all knowledge principle (C5). Morin (2015) explained that the retroactive principle represents a rupture with the linear idea of cause-effect and of product-producer, once everything that is produced turns on what produces it in a self-constitutive cycle. By turn, the reintroduction of knowledge in all knowledge principle places the individual as the center of the process. Morin and Le Moigne (1999) explained that all knowledge is a reconstruction/translation made by individuals at a particular time and in a particular culture.

The self-eco-re-organization (C6) principle begins with the concept of self-organization, which can be understood as the process by which elements interact to create patterns of behavior that are not directly imposed by external forces (Bar-Yam, 1997). By introducing the "re", the notion of continuous change and transformation is added; the "eco" brings the idea of interrelationships and dependency on the external environment (Morin, 2016b); and the "self" introduces the notion of autopoiesis, which involves the idea that systems entail a process of self-making or self-producing (Urry, 2005). As remarked by Dias et al. (2014), the self-eco-re-organization principle complements the notion introduced by the other principles by advancing in the notion of constant reorganization, leading to the idea that innovative firms operate in a dynamic state. According to Lichstenstein (2000), this assumption is extremely disruptive to the management science mindset: instead of asking "how and why does change occur in organizations?", the question now becomes, "why and how does stability emerge in a complex system?".

Finally, the dialogical principle (C7) assumes that notions that should exclude each other may not be inseparable in the same reality. Thus, antagonistic, complementary and competing phenomena may occur simultaneously (Morin, 2015). It incorporates paradoxal notions in order to capture the organizational, productive, and creational processes (Morin & Le Moigne, 1999).

This idea is present on the ambidexterity literature (March, 1991; Gibson & Birkinshaw, 2004). For instance, Uhl-Bien and Arena (2018) argued that for a organization to develop an innovation capability the role of leadership should be to enable an adaptive space to deal with the tensions between exploration and exploitation sides of the firm.

## 3. Method

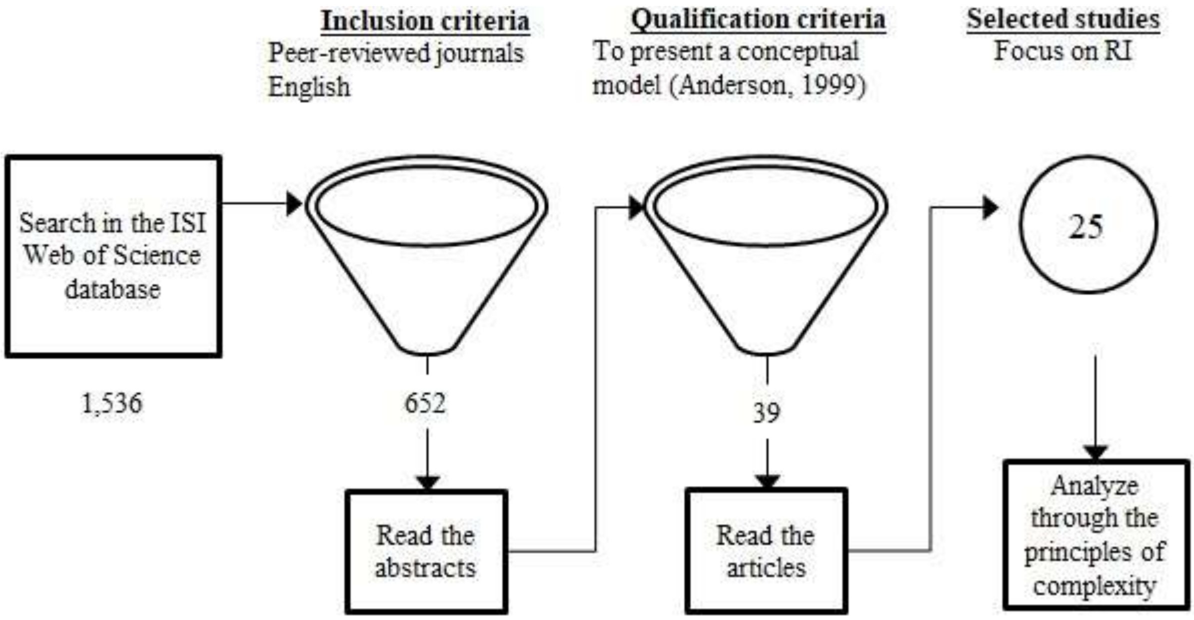
This study aims to analyze the innovation literature on RI management through the complexity lens. In order to meet this goal, systematic literature review was conducted. According to Cronin, Ryan, and Coughlan (2008), this method is characterized by the use of explicit and rigorous criteria to identify, critically evaluate and synthesize all the literature on a particular topic. Biolchini et al. (2007) explained that it is constructed around a central issue, which represents the core of the investigation, and follows a very well defined and strict sequence of methodological steps. As suggested by Tranfield, Denyer, and Smart (2003), the review process was structured into three stages: planning, conducting and reporting. The steps of each stage were adapted from Conforto, Amaral, and Silva’s (2011) roadmap.

In the planning stage, the objectives and protocol of the review were identified, which included defining clear criteria and process of selection of papers. The search on the databases was conducted as to capture the many variations of the term “radical innovation”. In addition, these variations were associated to the following keywords: “model”, “framework”, and “approach”. The research string was elaborated as follows: Topic: ("radical* innov*" OR "disrupt* innov*" OR "architect* innov*" OR "break* innov*" OR "competence* innov*" OR "discontin* innov*" OR "revolutio* innov*" OR “strategic innov*” OR “major innov*” OR “transformational innov*” OR “paradigm shift innov*”) AND Topic: (model OR framework OR approach).

The ISI Web of Science database was used due to the rigor of the evaluation process to which the published papers were submitted and also because a search of this database includes documents from other databases, such as Scopus, ProQuest, and Wiley. Inclusion criteria concerned the type of document (only peer-reviewed journals), knowledge areas (Management and Business), and language (English). The qualification criteria imposed that the paper must present a conceptual model related to the management of RI. A paper was considered qualified when meeting Anderson’s (1999) definition, that is a model is to encode a natural system into a formal system, compressing a longer description into a shorter one that is easier to grasp. Finally, the search considered all years as timespan and the Core Collection database of ISI Web of Science.

The second stage consisted of the actual review process. Initially, search was conducted and relevance of collected literature for the purpose of this study determined as showed in Figure 1:

Figure 1 – Selection steps and filters




Source: Authors (2021)

Initial search found 1,536 documents of which 652 met the inclusion criteria stated in stage 1. The researchers read the abstracts of the potential articles and verified the qualification criteria, resulting in 39 articles to be fully read. 25 papers focused on RI and were included in this study. Based on this set of papers, an iterative process of organization, codification and synthesis was initiated. For each article, an abstract was written including its main findings and contributions.

The final stage consisted of reporting the findings resulted from the analysis of the selected articles. The next sections describe the results and provide insights that emerged from the iterative process of analyzing the selected papers in the perspective of complexity. The contributions of the models are integrated and related to the principles of complexity.

## 4 Results

The selected RI models are shown in Table 1:

Table 1 – Selected RI models

| Author(s) | RI model |
|---|---|
| McKee (1992) | Cybernetic model of product development learning systems for RI |
| Lynn et al. (1996) | Opportunity definition phase of radical new product development |
| Veryzer (1998) | Radical product innovation process |
| O'Connor and Rice (2001) | Recognition of opportunities associated with RI |
| Rice et al. (2001) | Bridging the initiation gap (technologist vs. manager) |
| McDermott and O'Connor (2002) | Framework of strategy issues and challenges in managing RI |
| Reid and Bretani (2004) | Information Flow and Decision-Making Process for RI |
| O'Connor and De Martino (2006) | Discovery–Incubation–Acceleration |

| | |
|---|---|
| Birkinshaw et al. (2007) | Creating new networks in RI contexts |
| O'Connor (2008) | Systems model to develop RI capability |
| Cabrales et al. (2008) | Associating risk-taking attitudes within the team |
| Bers et al. (2009) | Accelerated Radical Innovation (ARI) model |
| Möller (2010) | New business fields emergence |
| Story et al. (2011) | Associating roles, role performance, and RI competences |
| Kelley et al. (2011) | Practices for managing project leaders for RI |
| Brentani and Reid (2012) | Assessment of Reid and Brentani's (2004) model effectiveness |
| O'Connor and Rice (2012) | Enabling and constraining mechanisms of RI teams |
| O'Connor and Rice (2013) | Uncertainty associated with RI |
| Büschgens et al. (2013) | Multi-level behavioral model for organizing for RI |
| Aarikka-Stenroos and Lehtimäki (2014) | Dynamic process model for the commercialization of RIs |
| Alexander and Knippenberg (2014) | Managing teams motivational states in pursuit of RI |
| Robbins and O'Gorman (2015) | Configuration perspective to team-based idea generation |
| Sadovnikova et al. (2016) | Conceptual model of the phenomenon of partnership |
| Pihlajamaa (2016) | Theoretical model of managing individual motivation |
| Gao et al. (2017) | Moderation mechanisms of market learning ties |

Source: Authors (2021)

### 4.1 A complex view of the fuzzy front-end activities

The fuzzy front end (FFE) is the root of success for firms involved with RI (Reidi & Brentani, 2004), comprising three activities: idea generation, opportunity recognition, and initial evaluation. Leifer et al. (2000, p. 26) explained that radical idea generation is likely to result from the synthesis of new and nonobvious insights from bits of disparate technical information. Opportunity recognition is a creative act and is defined as the match between an unfulfilled market need and a solution that satisfies the need (O'Connor & Rice, 2001). Initial evaluation is the process through which companies determine whether to commit the resources needed to develop the idea.

Rice et al. (2001) presented a framework for bridging the initiation gap, that is the gap between technical insight by technologist and the opportunity recognition by manager. The authors stated that triggering opportunity recognition and initial evaluation of RI typically starts with technologists, who are the generator of RI. O'Connor and Rice (2001) refer to scientists and engineers as generators. These authors recognize that simply rely on individuals is inefficient and propose management actions to enhance the likelihood of creativity to flourish.

Complexity principles may engender several insights on this matter. Anderson (1999) stated that work groups can be viewed as arenas in which new ideas emerge from the interaction of their members. More broadly, complexity turns attention to the interaction between any type of system's agents, i.e., individuals, groups or coalitions of groups, organizations, objects, or even concepts (Carlisle & McMillan, 2006).

Managers willing to address the challenge regarding FFE may benefit from the same ideas regarding agents' interaction provided by the complexity lens: new agents may be formed by recombining agents; agents coevolve with one another; agents are partially connected to one another, so that the behavior of a particular agent depends on the behavior of some subset of all the agents in the system (Anderson, 1999; Morin & Le Moigne, 1999; Carlisle & McMillan, 2005; Morin, 2010). The systemic principle underlies all these ideas. It is present in both

O'Connor and DeMartino's (2006, p. 477) proposal of structural aspects of RI management systems (Discovery–Incubation–Acceleration model), which is built on the assumption that since organizational elements often display high levels of coherence, changing one element of a system requires changing others; and O'Connor's (2008, p. 315) framework for building an RI dynamic capability, that assumes that each agent depends not only on conditions within itself, but also to a greater or lesser extent on the conditions within the whole.

Anderson (1999) explained that each agent's behavior is dictated by a schema, that is a cognitive structure that determines what action the agent takes given its perception of the environment. The recursive principle offers a insight regarding the relation between agent's schema and the environment. As suggested by Lynn, Morone and Paulson's (1996, p. 10) model, the form the developing technology should take depends on how the developing market responds to early versions of the technology; yet paradoxically, how the market responds depends on the form the technology takes. The dialogical principle is also present in this model: the firm may apply both market research and "probe and learn" strategies in the context of RI. A firm may enter an initial market with an early version of the product, learn from the experience, modify the product and marketing approach based on what they learned (Lynn et al., 1996, p. 19).

By viewing organizations as social complex systems, Braathen (2016) stated that the paradoxical experience may lead individuals and organizations to confusion and paralysis, or it may be a source for driving change and development. From a symbolic view, Aasen and Johannessen (2007) suggested that innovation can be understood as self-organizing emergence of everyday conversational patterns in which complex power structures come into play. Regarding the FFE and consistent with systemic and dialogical principles, the authors remarked that power structures may sometimes paradoxically both contribute (e.g., any kind of agent's interaction may produce new qualities in relation to the agents considered in isolation) and suppress (e.g., norms, procedures, and organizational culture may prune components' qualities) the innovation.

### 4.2 Managing complex projects while living with chaos

Leifer et al. (2000, p. 55) introduced the challenge of managing RI projects with the sentence "living with chaos". As a matter of fact, according to Poutanen, Soliman and Ståhle (2016, p. 205), the most valuable insight from the complexity perspective to the study of innovation is that the management rhetoric needs to abandon the traditional assumption that reality is well ordered, "unfreeze-change-refreeze" designed, and that organizations operate in a state of equilibrium.

The challenge of managing RI projects is closely related to interface management, that is managing between RI and mainstream parts of the organization (Leifer et al., 2000). Many authors of the models selected (e.g., O'Connor & Rice, 2013) refer to March's (1991) seminal work that focus the notion of reaching some kind of optimum balance between exploration and exploitation (Carlisle & McMillan, 2006). Complexity research suggests that the ideia of "balance" is problematic in rapidly changing environments as of RI contexts. As pointed out by Walby (2007, p. 454), complexity theory stood up to challenge the view of traditional system theories, according to which equilibrium is the norm to which systems would always return. Instead of stable balance, the system may be pushed towards a state of dynamic equilibrium (Brown & Eisenhardt, 1997; Poutanen, Soliman, & Ståhle, 2016) or shifting equilibrium (O'Connor, 2008, p. 324) – conditions in which change is ongoing and continual.

In managing RI projects – complexity view suggests –, rather than shaping the pattern that constitutes a strategy, managers should shape the context within which it emerges

(Anderson, 1999, p. 229). Controls and rules may be kept to a minimum and agents are given as much scope and support as possible to self-organize (Carlisle & McMillan, 2006). Meyer et al. (1998) contended that managers should establish and modify directions and boundaries – not actions – within which improvised, self-organized solutions can evolve. As explained by Mitchell (2009) and Tapsell and Woods (2010), self-organization is the result of agent's action on local knowledge, where there is neither a central controller to tell them what to do, nor does any actor have complete knowledge of the circumstances surrounding their actions.

On the other hand, as pointed out by Szulanski and Amin (2001), too much freedom can be problematic in human organizations. It can lead to a sense of chaos if not actual chaos, generate too many ideas and even lead to an organization losing touch with reality. Therefore, managers need to "live with chaos" (Leifer et al., 2000) by making the organization operate between the "edge of chaos" and "edge of stability" (Brown & Eisenhardt, 1997), that is successful managers neither rigidly plan nor chaotically react; instead, they enable adaptability (Uhl-Bien & Arena, 2018).

**4.3 Learning through complex networks**

Learning about markets for RI has to do with networks and ties, once a firm needs to interact with the actors in the innovation ecosystem (Leifer et al., 2000).

Birkinshaw, Bessant and Deldrigde (2007) made the point that building networks for managing RI may be obvious in retrospect, but at the time of its emergence the signals are ambiguous and vague. They suggest that networks can be an important source of new insights, competencies, and relationships for the firm as it attempts to make sense of the changes affecting its industry. In complement, Gao et al. (2017) studied moderation mechanisms of horizontal ties and vertical ties on market learning in RI contexts. The authors argued that managerial ties affect firms' innovation activities by not only contributing intellectual input to the innovation process but also directly shaping the focal firms' behavioral tendencies.

Complexity perspective suggests that networks can be viewed as dynamical systems. By doing this, Anderson (1999, p. 223) contended that models may gain explanatory power by taking into account how a continuous injection of energy is necessary to sustain a pattern of interactions in a network.

Tapsell and Woods (2010) explained that a dynamic network consists of many actors constantly acting and reacting to what other actors are doing. As a result, the system never settles at a determinate equilibrium, which refers to the above discussion on dynamic equilibrium, "edge of chaos", and self-organization; and also reflects the self-eco-re-organization principle (Morin, 2016b).

Markets for BIs do not necessarily evolve in ways that managers expect or that align with established performance metrics (O'Connor & Rice, 2012). In RI contexts, Lynn et al. (1996) explained that market and technology are ill-defined and evolving, and that the two interact. Because the process is so long and dynamic, both may look entirely different at the end of the process than it did at the beginning, as of the competitive and regulatory environment. That is why the challenge regarding learning about markets for RI is crucial.

In this sense, we can look at McKee's (1992) model and O'Connor's (2008) systems approach to develop RI capability through the lens of the recursive, retroactive, and reintroduction of knowledge principles. Systems learn through single loops, that emphasizes repetition and routine and occurs within a given organizational framework, i.e., objectives toward which the system is evolving are never questioned (O'Connor, 2008); double loops, which involve changing what and how the organization do things; and meta-learning, related to the firm's aim of institutionalizing innovation (McKee, 1992). Complexity suggests that knowledge is as a reconstruction/translation made by individuals, meaning that the organization, besides creating mechanism of learning, it should be aware that any knowledge is changed by the individual's world view.

### 4.4 The self-organization enabler and the emergence of the champion

Individuals in charge of "grabbing lightning" (O'Connor, Leifer, Paulson, & Peters, 2008) and of seizing unique opportunities are not always as motivated, persistent, and willing to take risks by enthusiastically as the champion literature would lead one to believe (O'Connor & Rice, 2001; O'Connor & DeMartino, 2006). As remarked by O'Connor, Corbett and Peters (2018, p. xxi), "while project champions are both the bane of their managers' existence and the glory of their companies' folklore, they are extremely rare", so an organization can not rely on these unique individuals for developing a RI capability.

To address this issue, the complexity leadership theory (Uhl-Bien, Marion, & McKelvey, 2007; Uhl-Bien & Arena, 2017, 2018) may be an alternative. Moreover, it may be useful to overcome mainly, but not limited to, the challenges regarding competency gaps and individual initiative engagement.

Uhl-Bien and Arena (2018) argued that literature have considered individual adaptability, team adaptability, leader ambidexterity, and networks, but discussions of leadership for organizational adaptability are largely missing. The authors contended that leadership for organizational adaptability is different from traditional leadership. In the same vein, Sawhney and Prandelli (2000) explained that instead of "commandant-control" planning towards well-known goals, complex systems call for a leadership that promotes the richest possible environment for self-organization to occur – champions may act as self-organization enablers.

In line with previous discussions on dynamic or shifting equilibrium (O'Connor, 2008; (Poutanen, Soliman, & Ståhle, 2016), Uhl-Bien and Arena (2018) proposed the concept of adaptive space to explain how organizations become highly adaptive and innovative. It can be understood as the conditions that allow for adaptability to occur in a system. As explained by Anderson (1999), adaptation is the passage of an organization through an endless series of organizational microstates that emerge from local interactions among agents. Adaptive spaces are not part of our natural organizations, they need to be created. Rather than create order and certainty, it is about creating a space for people to be able to look for emerging properties. From this perspective, the role of the leader is to accept and even promote uncertainty (Uhl-Bien & Arena, 2018, p. 95). This points directly to the dialogical principle (Morin & Le Moigne, 1999; Morin, 2015), once established companies found themselves with reduced capacity to cope with highly uncertain domains (Leifer et al., 2000; De Meyer, Loch, & Pich, 2002; Rice, O'Connor, & Pierantozzi, 2008).

Finally, complexity supports the claim that champions emerge (Kelley, O'Connor, Neck, & Peters, 2011). Many authors stated that; complexity may be an alternative to explain. Champions do not emerge from nowhere, but from the interaction of structural, behavioral, cognitive and political elements of an organization. This occurs in the adaptive space, which is generated by the tension between the "need to produce" and the "need to innovate" sides of the company and is enabled by leaders. Accordingly, the hologramatic and recursive principles instigate us to think that the "emergence of the champion" is not simply an outcome or the end of a process; it is part of a non-linear, self-production cycle in which the products and effects are themselves the producers and cause of what they produce (Morin & Le Moigne, 1999, p. 210).

## 5 Conclusion

As told by the Executive Chairman of Cisco, a company disrupt or is disrupted (Chambers, 2016). To develop RIs an organization need to operate in a state of dynamic or shifting equilibrium (Brown & Eisenhardt, 1997; O'Connor, 2008; Poutanen, Soliman, & Ståhle, 2016) in order to cope with the complex changing environment that characterizes it (Leifer et al., 2000; McDermott, & O'Connor, 2002).

The principles of complexity are useful in generating insights on this matter, as summarized in Table 2. This paper provides a broad view of the application of complexity research in managing RI by connecting the principles of complexity with managerial challenges of RI.

Table 2 – Complexity insights to the management of RI

| Principle of complexity | Complexity insights |
|---|---|
| Systemic | A work group may be seen as arenas in which any type of agents (people, teams, objects, concepts) may interact giving emergence to innovative ideas<br>New agents may be formed by recombining agents and coevolve with one another<br>The behavior of a particular agent depends on the behavior of some subset of all the agents in the system |
| Hologramatic | The "emergence of the champion" may be understood as a non-linear, self-production cycle in which it is the same time product and effect of the process |
| Recursive circle | The form the developing technology should take depends on how the developing market responds to early versions of the technology; yet paradoxically, how the market responds depends on the form the technology takes |
| Retroactive circle and reintroduction of knowledge in all knowledge | Besides creating mechanism (learning loops) of learning, the organization should be aware that any knowledge is changed by an individual's world view |
| Self-eco-re-organization | Innovation can be understood as self-organizing emergence of everyday conversational patterns<br>Managers should establish and modify directions and boundaries – not actions – within which improvised, self-organized solutions can evolve<br>Leaders may act as self-organization enablers by promoting the richest possible environment for self-organization to occur |
| Dialogical | Power structures may paradoxically both contribute and suppress the innovation<br>A firm may apply both market research and "probe and learn" strategies in the context of RI<br>At the same time that companies may found themselves with reduced capacity to cope with highly uncertain domains, the role of the leader is to accept and even promote uncertainty |

Source: Authors (2021)

Morin's understanding of complexity was used due to the recognition of the author as one of the most prominent researchers on complexity and to whom is attributed the development of the philosophy of complexity, but there is a myriad of complexity-based approaches that may be explored (see Castellani, 2018). This study can be broadened through the integration with other complexity-based approaches.

This study may contribute to further studies to provide: *i*) More in-depth analysis of the managerial challenges of RI; *ii*) Discussions on how each principles of complexity may be useful to the management of RI and to the innovation literature and practice in general; and *iii*) Developing tools to operationalize the knowledge about complexity in actual innovation management practices.

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