



Beyond Open Access: Conceptualizing Open Science for Knowledge Co-creation

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Despite the calls from European Union (EU) and global institutions, such as UNESCO and Organization for Economic Co-operation and Development (OECD) for more openness and collaboration between Quadruple Helix actors (government, academia, industry, and civil society), in practice, scientific knowledge creation has been much more closed and fragmented. As an emerging field of study, Open Science (OS) for knowledge co-creation currently requires significantly conceptual and theoretical challenges to be addressed before advancing to practical application. To address this gap, the paper aims to develop a conceptual framework integrating diverse understandings of OS beyond the use of Open Access (OA) and data practices. The author argues that OS should be approached as a complex ecosystem with the potential for knowledge co-creation and social innovations. The underlying premise of the proposed conceptual model is the interdisciplinarity in integrating multiple reference disciplines. Such an approach allows us to learn from other disciplines and contribute to OS research through the emergence of new ideas for theory and practical application. Consequently, a dyadic model is presented where (1) framework conditions regulate how (2) systemic conditions can realize their full potential for knowledge co-creation resulting in outputs (e.g., collaborative projects and citizen science projects) and outcomes (e.g., social innovations, higher quality of science, and democratized knowledge) beneficial for a broad spectrum of stakeholders.

Keywords: Open Science, co-creation, stakeholder engagement, science communication, evaluation model, citizen science

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INTRODUCTION

The term “Open Science (OS)” has its origins in the Open Access (OA) movement which started in the 1990’s with the rapid development of digital technologies (Wolff and Schlagwein, 2021). Today, its definition goes beyond the sharing of research data and use of open software/hardware, and includes knowledge generation through transdisciplinary research, university-driven interactions, citizen science, science communication, and intensified Quadruple Helix (i.e., government, academia, industry, and civil society) relations (European Commission, 2021a). European Union (EU) and international institutions, such as UNESCO and Organization for Economic Co-operation and Development (OECD) started to include the engagement and openness discourse into the research and innovation agendas in parallel with digital advancements (OECD, 2021; UNESCO, 2021). The openness narrative also intensified amid the Coronavirus outbreak unveiling the need for rapid scientific data sharing and global interdisciplinary collaborations (OECD, 2020).

Research points to a greater awareness of the scientific process as a result of the non-academic stakeholder engagement (Goi and Tan, 2021). The stakeholders also enjoy the scientific results

through an increase in knowledge and practical improvements in their life (Goi and Tan, 2021). New forms of engagement are based on the principle of co-creation where “value” is created as the nexus of interaction (Osborne et al., 2018). Hence, they also have the capacity for social innovation through tackling social problems unaddressed by governments and commercially motivated actors.

Despite the calls for more openness and co-creation, in practice, scientific knowledge development is still largely closed and fragmented. This stems from systemic problems such as research evaluation practices based on the number of citations and journal impact factors, scientific policies focused on commercialization, asymmetric information distribution, and lack of competitive governance. In addition, the OS research field itself lacks clarity. The academic understanding of OS is diffuse and lacks evidence-based guidelines on how to make OS practices beneficial for all. As an emerging field of study, OS for knowledge co-creation needs to address significant conceptual barriers before advancing to broader practical application.

To address this gap, the paper proposes a conceptual framework integrating diverse understandings of OS. First, the perception of OS is actualized using two frames of understanding defined by Freiling et al. (2021): (1) OS as a quality control measure and (2) OS as a way to ensure the social duty of science. This is followed by an integrative literature review of multiple disciplinary insights on value co-creation in complex systems, i.e., innovation ecosystems (e.g., Adner, 2006; de Vasconcelos Gomes et al., 2018), social innovation ecosystems (e.g., Domanski et al., 2020; Terstriep et al., 2020), open innovation (Chesbrough, 2003), and ecosystems of shared value (Kramer and Pfitzer, 2016). Next, a conceptual framework is proposed by defining the complexity of factors influencing the co-creation processes in OS. The author argues that OS should be approached as a complex ecosystem with the potential for knowledge co-creation. In contrast to the linear process approach, the ecosystem view emphasizes complexity in terms of interdependencies between a variety of stakeholders and their different expectations and capacities. Finally, the theoretical and practical implications of the proposed framework are discussed together with recommendations for further research.

OPEN SCIENCE: TWO FRAMES OF UNDERSTANDING

The previous research includes efforts summarizing the plethora of OS. For example, Fecher and Friesike (2014) identified five schools of OS thought (i.e., infrastructure, public, measurement, democratic school, and pragmatic school). In a similar exercise, Vicente-Saez and Martinez-Fuentes (2018) concluded that OS can be defined as knowledge which transparent, accessible, shared, and collaboratively developed. However, OS is still an evolving concept and it might be too early to stick to one typology. Thus, in this work, a broader approach is adopted through the objectives defined by Freiling et al. (2021) highlighting the duality of OS discourse: (1) the capacity for quality control of science (i.e., making sure

objectivity is a central part of research) and (2) the capacity in ensuring the social duty of science (i.e., ensuring maximum benefits of their work to societies which invest in their work). These two objectives are inevitably interlinked as they share ontological principles of openness, transparency, and reproducibility. The next sections will review these two lines of academic thought.

Open Science as a Quality Control Measure

The problems of plagiarisms, data falsification, and research-related biases are well documented (e.g., Wicherts et al., 2016; Cook et al., 2018). However, replication studies that can combat such academic misconduct are scarcely practiced (Camerer et al., 2016; Mueller-Langer et al., 2019). Researchers (Fisher, 1935; Popper, 1959; Sackett, 1979; Dickersin, 1990) have already raised concerns regarding reproducibility several decades ago. However, the sheer number of publications being produced today made the problem as painful as ever. Other related issues are also under broad discussion. For example, the pressure to publish in academic employment and funding acquisitions (Nosek et al., 2012) and the reluctance to share the scientific data (Stodden, 2015). The practices of OA (Piwowar et al., 2018), Open Peer Review (Wolfram et al., 2020), Open Data and Source (King, 2011; Pasquetto et al., 2015), and OS Notebook (Bradley, 2016) have been developed to address this lack of reproducibility and openness. The academic narrative on OS also includes discussions on the ethical aspects of scientific research (Franzoni and Sauermann, 2014). A promising, new development addressing the ethical considerations is the FAIR standards referring to the need for data to be Findable, Accessible, Interoperable, and Reusable. Kramer and Bosman (2016) outlined that openness practices already made a positive influence on the research process and circulation of scientific knowledge.

Since 2006, European Commission invested heavily in the development of required infrastructures at the European level (European Commission, 2021b). Some notable examples include a series of OpenAIRE, Open Research Europe, and European OS Cloud projects serving as pilots for mainstreaming the openness infrastructure (European Commission, 2021b). In addition to the infrastructure, European Commission used the Framework programs (FP) for integrating openness elements into Research and Innovation (R&I) landscape. A gradual change in the way OA and data were approached in FP can be seen. Under the seventh FP (2007–2013) a pilot on OA was launched and in the eighth FP Horizon 2020 (2014–2020) OA to all peer-reviewed scientific publications became mandatory. The new FP (Horizon Europe) demands immediate OA, including both the right to read and reuse the materials (European Commission, 2021a). The outcomes of these policies are already apparent. According to the study “Monitoring the open access policy of Horizon 2020” conducted in 2021, “estimated level of compliance to the open access mandate for scientific publications under Horizon 2020 stood at 83%” (European Commission, 2021b, p. 10).

The OS movement extends beyond the EU. For the past decade various international bodies debated the OA policies (e.g., 2002 Budapest OA Initiative, 2016 Amsterdam Call for Action

on OS and global initiatives) and developed the key principles in data and information sharing (e.g., OECD Principles and Guidelines for Access to Research Data from Public Funding). In 2016, the African OS Platform was launched (African OS Platform Strategy Workshop, 2018). Major open research data initiatives are underway in Australia, Canada, and China (UNESCO, 2021).

Despite positive changes in openness infrastructure, problematic areas of OS application prevail. For example, predatory publishers exploiting OA requirements (McCann and Polacsek, 2018), a limited number of high-quality OA journals, and the academic promotion and evaluation system, where OA is not of major importance. Research shows that researchers seem to be in favor of the general concepts of OA and open data (Ross-Hellauer et al., 2017) but are hesitant to publish OA and rank OA availability as low when considering where to publish (Blankstein and Wolff-Eisenberg, 2019).

Open Relations Between Science and Society

Over the past few decades, academic research focused on organizational openness with implications of greater transparency and inclusion (Whittington et al., 2011; Hautz et al., 2017). Such relationships share one underlying albeit opaque principle of co-creation. In general, co-creation refers to the bi-directional, interactive development of new knowledge together with a diverse group of stakeholders. In the research and innovation context, the views seem to also be shifting toward opening the processes to citizens and other stakeholders. For example, the EU FP fosters open collaborations with non-academic partners. Gagliardi et al. (2016) and Greenhalgh et al. (2016) described participative approaches in science as Mode 2 learning where knowledge is created with those who are likely to use it, within the context of its use, and where boundaries between users and producers of knowledge are blurred. The research already includes qualitative (D'Este et al., 2018) and quantitative (Mascarenhas et al., 2018; Sjöo and Hellström, 2019) evidence based on the societal and the economic benefits of open collaborations.

There is a large literature on co-creative initiatives in science, for example, transdisciplinary research (OECD, 2020), university-driven interactions (D'Este and Perkmann, 2011), citizen science (MacSweeney et al., 2019), and Triple Helix relations between universities, industry, and government (Etzkowitz and Leydesdorff, 2000). Currently, one of the most discussed open collaborative practices is citizen science. Here, the public participation is achieved through (1) crowdsourcing initiatives mobilizing voluntary contributions by non-researchers such as iNaturalist or Zooniverse and (2) initiatives aimed at citizen intervention and empowerment in the course of research itself, such as the definition of research problems or project coordination (MacSweeney et al., 2019). Citizen science approaches are growing among many research disciplines, most notably in environmental science, climate change, health, and biomedical research. Some applications are already apparent in social sciences and humanities (Tauginiene et al., 2020).

Despite the benefits of co-created research, it can face significant barriers. The academic community tends to collaborate with similar actors due to different institutional conditions (van Rijnsoever and Hessels, 2021). Co-creative initiatives require significant resources and continuous investments in project management, processes, and staff to overcome organizational and knowledge differences (Pinho et al., 2014; Whitmore and Mills, 2021). What complicates the work with non-academic partners even more is the lack of required skills in academia (European Commission, 2021a). However, training and guidance opportunities for researchers willing to engage with actors unfamiliar with scientific routines are limited (European Commission, 2021a). The academic literature is more concerned with collaborations with industry (European Commission, 2021a). In general, research on co-creation through OS initiatives focuses on conceptualization rather than on deconstructing the collaboration dynamics between researchers, civil society, government, and industry (Stier and Smit, 2021). Aguinis et al. (2020) used motivation theory to explain why there is a gap between the knowledge and practical application of OS and concluded that the perceived costs of openness are currently higher than the benefits. This suggests that a systemic change is needed for OS to gain traction.

TOWARD AN INTEGRATED UNDERSTANDING OF OS FOR KNOWLEDGE CO-CREATION

The two frames of understanding discussed in the section above, showcase that current research and practice are much more focused on the quality control measures in OS. The field fails to provide science-based recommendations on developing and sustaining the co-creative processes with non-academic partners. A similar conclusion was reached in the 2020 UNESCO multi-stakeholder consultation on OS. It was noted that the OS policy system is fragmented and appears to be a collection established by individual universities and research funding agencies (UNESCO, 2020). Given the centrality of the co-creation concept in OS discourse, contemporary research must deepen the understanding of the phenomenon in science and innovation systems. To address this gap, the author works on developing a conceptual framework that details how science and innovation systems could be designed as structures for knowledge co-creation through the application of the OS approach.

Analysis and evaluation of complex paradigms go beyond a scope of a single theory. Hence, the underlying premise of the proposed conceptual model is the interdisciplinarity integrating multiple reference disciplines dealing with co-creation in complex multi-agent systems. This approach will include an integrative literature review of multiple disciplinary insights in an integrated fashion. Integrative literature reviews are relevant in addressing new and emerging topics which could benefit from a holistic conceptualization (Torraco, 2016). The review is not systematically organized to rely on predetermined keywords, as the researched phenomenon is emergent and lacks common terminology. The author first identified the literature

fields that address knowledge co-creation in complex systems and within these fields, reviewed and synthesized any research that might be seen to contribute to understanding the factors shaping co-creative processes. The initial literature review resulted in the identification of fields offering varying perspectives of co-creation: open innovation ecosystems, knowledge ecosystems, triple and quadruple helix innovation, and social innovation ecosystems. Next, the author looked into how these fields characterize co-creation (i.e., how ecosystems could be developed as structures for knowledge co-creation). Theoretical and practical insights were harmonized into more general dimensions and concepts. The result of the integrative literature review is a conceptual framework allowing exploration of the OS scope for knowledge co-creation, its links with organizational, socio-cultural, and technological factors, and dynamics of multiple stakeholders (citizens, communities, researchers, policymakers, etc.) in a defined context.

Open Science Ecosystems as Structures for Co-creation: A Conceptual Framework

The traditional innovation theories provide a linear view of one-directional flows from science to the commercial application (Arnkil et al., 2010). Recent academic thought increasingly acknowledges that complex knowledge is needed in addressing social and environmental challenges. Such knowledge cannot be

generated within the boundaries of a single organization (Kazadi et al., 2016). Following this paradigm change a variety of new methods and theoretical approaches were defined deconstructing collaborative practices of new knowledge creation (Vargo and Lusch, 2016; Järvi and Kortelainen, 2017). In reviewing them, the notion of ecosystem revealed its importance with different qualifiers such as innovation ecosystem (e.g., Adner, 2006; de Vasconcelos Gomes et al., 2018), social innovation ecosystems (e.g., Domanski et al., 2020; Terstriep et al., 2020), open innovation (Chesbrough, 2003), ecosystems of shared value (Kramer and Pfitzer, 2016). Although functional purposes may vary, the concepts increasingly overlap and share certain inherent features. Mostly because collaborative approaches assume that within complex systems there is more capacity for new knowledge generation than as an individual. In most cases, the actors enhance their capacities by acting together (Jütting, 2020). What makes the concept of innovation ecosystems distinct from other forms of collaboration is the value of co-creation for all stakeholders involved and attention not only to structural conditions of innovation (i.e., funding and infrastructure) but also to intangible and qualitative interactions (Cai et al., 2020). Thomas and Walburn (2017) underlined the need to look beyond structural capital and consider human (i.e., people, skills, networks, and knowledge) and relational (i.e., trust, confidence, and shared vision behavior) capital in innovation ecosystems.

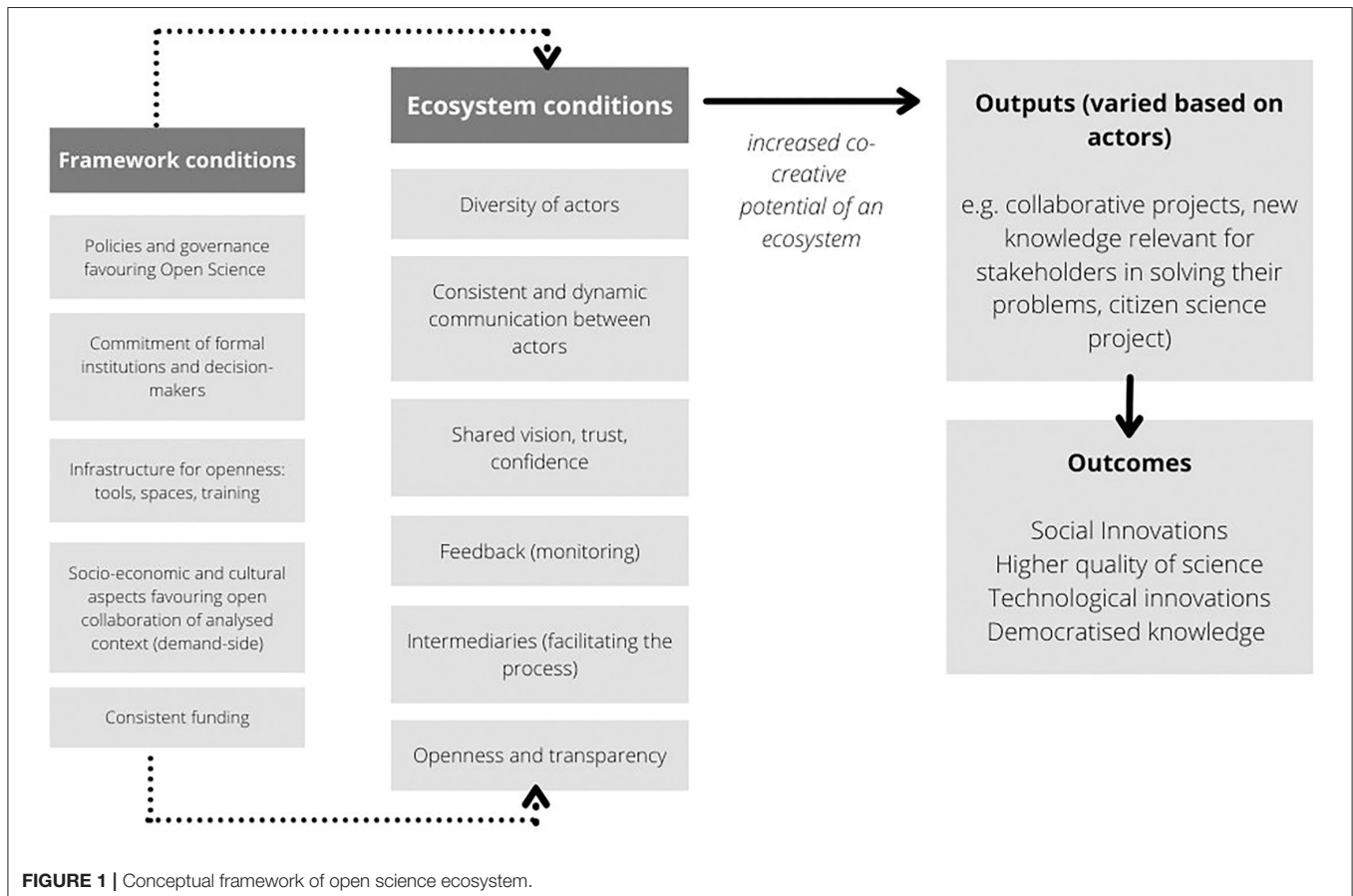


FIGURE 1 | Conceptual framework of open science ecosystem.

Based on the outlined consideration, the author argues that knowledge co-creation processes in OS should also be approached through the view of the ecosystem since it embraces a much wider socio-cultural system than pure dyadic relationships between research/industry or research/civic society. Traditional conceptualizations of OS focus on policies, infrastructures, and funding that support the openness paradigm similarly to other contexts of innovation. Hence, by broadening attention to the ecosystem more intangible and qualitative aspects affecting knowledge co-creation can be isolated. Such an approach provides a more holistic understanding including both the objective (i.e., quality improvement measures) and subjective goals (i.e., the social duty of science) of OS. Hence, the proposed conceptual framework (see **Figure 1**) suggests that the co-creative capacity is determined by a complex set of interactions grouped along two dimensions: *framework conditions* and *ecosystem conditions*.

Framework Conditions

The *framework conditions* focus on structural factors that are amendable through policy interventions. Structural factors provide an enabling environment for actors to engage in co-creation activities. According to Remøe et al. (2015), there is no such thing as generally optimal framework conditions because of varying conditions in different countries. However, certain characteristics can be seen as conducive to innovation. This includes policies and governance favoring OS approaches, the commitment of formal institutions and decision-makers, infrastructure for openness in terms of tools, spaces, and training available for actors willing to participate in collaborative research activities, consistent funding for openness initiatives, and socio-economic and cultural aspects in analyzed context. Implicitly, this means that the capacity to co-create depends on a wider economic and institutional environment.

Ecosystem Conditions

The *ecosystem conditions* refer to the dynamics (linkages and networks) of the co-creation process. Although the OS researchers agree on the importance of co-creation as a new type of organizing, how to design them for co-creation to happen is researched to a much lesser extent. This is in part because the concept of value co-creation itself is elusive (Grönroos and Voima, 2013). However, some research is moving in this direction and will be discussed in the following section. Ketonen-Oksi and Valkokari (2019) looked at innovation ecosystems as structures for value co-creation and identified the key principles based on empirical findings: ensuring a clear vision and a shared value base on which the ecosystem activities can be built, facilitation for actors to make new connections and share their knowledge, and diversity among ecosystem actors. Pera et al. (2016) found that the enablers of multi-stakeholder value co-creation are trust, openness, and inclusiveness. Kramer and Pfitzer (2016) analyzed the ecosystems of shared value and defined five elements leading to collective impact and social change: common agenda, shared measurement system,

mutually reinforcing activities, constant communication, and dedicated “backbone” support from one or more independent organizations.

Other complexity-based ecosystem studies focused only on particular elements of the co-creative process such as communication, heterogeneity, and roles of different actors. Ruoslahti (2018) argues that multi-stakeholder communication is a key process in networked activities which leads to the reduction of knowledge gaps and complexity. The heterogeneity of actors involved in ecosystems is increasingly recognized in collaborative innovation and refers to a wide variety of Quadruple Helix partners (Corsaro et al., 2012). However, few studies identify the exact number and diversity of stakeholders required (Reypens et al., 2016). Corsaro et al. (2012) based on previous literature identified six attributes of actors’ heterogeneity that influence the development of collaborative innovation: goals, knowledge bases, capabilities and competencies, perceptions, power and position, and culture. This shows the importance of capacity evaluation of different stakeholder groups (i.e., can and how they can participate in ecosystem processes). Terstriep et al. (2015) distinguished four categories of actors involved in social innovation processes: developers, promoters, supporters, and knowledge providers. Terstriep et al. (2015) suggested that actors may fill a number of these roles and they are subject to change over time. There is also extensive literature on innovation intermediaries providing support for collaboration between two or more actors and bridging gaps in knowledge, competency, and capability (Edler and Yeow, 2016). Universities seem to play an essential role in innovation ecosystems as knowledge integrators (Cai et al., 2020; Tolstyk et al., 2021).

Some research already looked into the possible solutions for decreasing the fragmented implementation of OS. For example, Tabarés Gutiérrez et al. (2020) after analysis of an EU-funded project identified five pillars of openness implementation: (1) contextualization (institutional self-understanding that takes into consideration the structures, rules, and values of the target organization and institutional field); (2) ecosystem approach (institutional embeddedness, network relationships, and interdependencies of the target organization); (3) organizational theory (theoretically and empirically grounded framework for the organizational change); (4) metrics and indicators (qualitative and quantitative impact assessment); and (5) communication, culture, and trust (open communication to build and maintain trust). Dobers and Stier (2018) have listed recommendations for organizations that work with quadruple helix collaboration and co-creation in social sciences and humanities fields. The research has divided them into four categories: management, involvement, communication, and tools and spaces. Regeer and Bunders (2009) looked into interactions between science and society and defined success factors for interactive approaches at four levels: system-level (network is adaptive and provides learning opportunities), institutional level (organizational embedding, support for co-operation, possibility of changes in the process, stimuli, financing, and adequate funding criteria), project level (project leader/core and process management), and participants (committed to shared objective, open, listening, and skills for

joint learning). Similarly, Ruoslahti (2018) looked at the co-creation of knowledge in EU-funded innovation projects based on the elements of complexity and emphasized self-organization, connectivity and interdependence, co-evolution, and the creation of new order. However, a more cohesive and holistic framework of evaluation has not been offered by the researchers.

Although the definitions of factors shaping co-creation processes in complex multi-agent ecosystems are varied, key properties can still be derived into the conceptual framework from the above discussion, i.e., heterogeneity in terms of actors involved (belonging to different social and technological networks), shared vision (to base the ecosystem activities), support system (institutional and non-institutional), feedback and measurement mechanisms (for continuous self-regulation), consistent and dynamic communication (between the actors of the ecosystem), and intermediaries facilitating the processes (of making new connections and resource integration).

DISCUSSION

The dyadic approach provides a portrayal of national research and innovation systems where framework conditions regulate how systemic conditions can realize their full potential for knowledge co-creation resulting in outputs (e.g., collaborative projects and citizen science projects), and outcomes (e.g., social innovations, higher quality of science, and democratized knowledge) beneficial for a broad spectrum of stakeholders. This is especially needed given that science and innovation ecosystems are highly dependent on framework conditions (differently from market-oriented ecosystems). It is important to note that, the variety of actors involved and the non-linear nature of the process means that co-creation might not have one final result. Rather a variety of less specific, broader directions toward more openness. This feature turns the measurements and assessment into a highly complex procedure. Hence, the proposed model only focuses on the increased potential of the ecosystem to co-create value (knowledge). Although causal relations within the ecosystem and the effects on value co-creation have not yet been studied sufficiently, the dual approach offers valuable elements for an improved understanding of OS performance. The conceptual framework provides a theoretical platform for future research on OS ecosystems in different countries and regions. Further conceptual elaboration and empirical research are needed to confirm the elements of the framework and continuously adapt it.

CONCLUSIONS AND IMPLICATIONS FOR RESEARCH AND PRACTICE

Open Science is a rapidly expanding and diversifying field of innovation with significant implications for and potential benefits to society, policy, and various academic research areas. In facing global challenges, scientific knowledge development needs to leverage the strength of different stakeholder groups and find new ways to control the influx of information (citizens

thinking like scientists, the importance of critical thinking). With a fragmented scientific and policy environment, a universal understanding of the meaning, opportunities, and challenges of OS is still missing. The research presented in the article showed a lack of studies on how to use OS to engage and manage multiple stakeholders, what are the parameters for achieving innovation and new knowledge, and how to ensure that the knowledge is not only co-created but relevant and applicable in different contexts. Current research and innovation systems are not designed with co-creation in mind hence both framework (i.e., structural changes in terms of policies and funding) and co-creation process changes are needed.

The proposed conceptual framework structures the available research on knowledge co-creation in complex systems and adapts it to the research and innovation context. First, the research examines the conceptual essence of OS theory and practice. Second, the research integrates research already conducted on co-creation in complex multi-agent ecosystems to capture the multiple dimensions of the concept and adapts it to a conceptual framework. Hence, from a scientific point of view, the research contributes to the literature by deconstructing the social rather than technological links in OS development by emphasizing the importance of evaluating the collective actions of multiple stakeholders in creating innovations. The practical importance of this analysis is to provide insights for policy-makers on how to facilitate co-creation through OS measures, i.e., what framework conditions influence the co-creative performance of an ecosystem. Effective management of knowledge co-creation can strengthen the confidence of the public in the science system and enable collective problem-solving in multiple contexts.

The research presented has several limitations which could be improved in the future. First, the definition of complex and emergent socio-technical systems is unavoidably partial, context-specific, and temporary. Additional work is needed to formulate measures and indicators of successful co-creation initiatives in OS. There is a need to examine not only the processes of value creation but also value capture. It is hence important that more and more research would document the methods of co-creation in research and innovation systems.

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MM made substantial contributions to the conception and design of the work, acquisition, analysis, and interpretation of data for the work, and drafting and revising it critically for important intellectual content.

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