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Open Science Philosophy and Paradigm of Scientific Research

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***Abstract*—**This paper presents the open science philosophy and paradigm of scientific research on how to transform classical research and innovation approaches. Open science is the practice of providing free and unrestricted online access to the products of scholarly research. Open science advocates for the immediate and unrestricted online access to published, peer-reviewed research in digital format. Open science research is made available for free in perpetuity and includes guidelines and/or licenses that communicate how researchers and readers can share and re-use the digital content. The emergence of open science has changed the scholarly research and publishing landscape, making research more broadly accessible to academic and non-academic audiences alike. Consequently, open science philosophy and its practice are discussed to cover all aspects of cyberscience in the context of research and innovation excellence for the benefit of global society.

***Keywords*—**Open science, open data, open access, cyberscience, cybertechnology.

I. Introduction

OPEN science aims at transforming science through cybertechnology, to make research more open, global, collaborative, creative and closer to society. Open science refers to designate a form of science based on open source models, or that utilizes principles of open access, open archiving and open publishing to promote scientific communication. Open science increasingly also refers to open governance and more democratized engagement and control of science by scientists and other users and stakeholders. Open science is about the way research is carried out, disseminated, deployed and transformed by digital tools, networks, and media. It relies on the combined effects of technological development and cultural change towards collaboration and openness in research. Open science means a radical transformation of the nature of science and innovation due to the integration of cybertechnology in the research process and the internet culture of openness and sharing. It is more open, more global and collaborative, more creative, and closer to society. It relies on the use of cyberinfrastructures, i.e., cybertechnology - based services and tools for data - and computing-intensive research in virtual and collaborative environments [5].

Open science makes scientific processes more efficient, transparent and productive by offering new tools for scientific collaboration, experiments and analysis and by making scientific knowledge more easily accessible. Openness is also an essential aspect of the ethics of science by which researchers are bound by expectations to share their work openly and to make public their methods and procedures as much as the data or results. Therefore, researchers should be open to criticism and participate in the review of scientific work. Open science's peer review depends on openness. Openness prevents science from becoming dogmatic, uncritical and biased. Open peer review indicates that the nature of digital media of scientific communication may also offer some extension to the peer review system. Open science institutions provide an alternative to the intellectual property approach to dealing with severe problems in the allocation of resources for the production and distribution of scholarly information. While open peer review procedure is taken as the principal mechanism that enshrines the value of community criticism or self-evaluation and offers the means for quality improvement that constitutes the essential openness of scientific communities, the ideal and process are not immune to change, criticism and revision. In some ways, the development of the open science peer-review system echoes the transformation movement from the "small science" to the "big science" of the digital age.

The global scientific community faces a significant transition with the rise of open science that involves the possible end of science hyperpowers and the beginning of a more articulated open system based on open source models of intellectual property and large scale international collaboration. Increasingly, global scientific community stresses open science as an efficient means of addressing scientific problems of global significance that spill across borders. Open access practices make scientific progress more collaborative and therefore more productive. Open science publishing promotes live publishing, removes price barriers to communication, improves collaboration between authors, researchers, readers, and publishers, and promotes a paradigm change in approach and openness. The scope of the philosophy of open science encompasses, openness to freedom, openness to the other, openness to experience, openness to criticism, openness to interpretation, open science governance, and open science communications technologies. Naturally, these open science philosophical principles developed over time to form the composite core of a responsible and public science in the service of humanity.

Open science, as an open system, embraces openness and examines how openness defines the practice of science, provides the drivers of change, highlights new ways of doing science-based computing and communication and encourages greater communication with citizens, allowing better review of the evidence that underpins scientific work, but also reclaiming something of the public purpose of science from the hands of experts. There is no doubt that it is the age of open science. Open science defines the future of science in the age of cybernetworks and the nature of open peer review.

Open science makes it possible not only to perform research more efficiently but to transform science. However, there are specific policy challenges relating to harnessing its full potential: changing traditional research systems and cultures to better appreciate openness and collaboration; ensuring the widest possible take-up by research organizations and different disciplines; addressing possible risks and adverse effects. Open science development is being promoted by open science coordination, cyberinfrastructures development, and various research actions, with collaboration links to other digital services. Through open science policy and global research area, open science:

- supports developing open science tools and practices;
- supports open science capacity both in terms of cyberinfrastructures and human capital; and
- provides leadership and guidance through policies for taking up open science practices and for ensuring that the related risks and challenges are addressed.

Open science ensures that the recognized objects of inquiry for open science are addressed in the respective parts of the global research area as well as in the overall approach. Concretely, open science policy contributes to developing open science on different levels:

- Technologies and components for data gathering and networked systems
- Models, methods and tools for future research and information processing
- Platforms and infrastructures which can support collaborative research
- Innovations for open science, developing an understanding of the related challenges

Open science approaches should be systematically encouraged to embrace open science, when appropriate. Cybertechnology has profoundly changed the ways knowledge is created, communicated and how it can be further deployed. It has made possible a radical transformation of the nature of science and innovation. This open science relies on the use of cyberinfrastructures, i.e., cybertechnology - based services and tools for data- and compute-intensive research in virtual and collaborative environments, combined with an internet culture for openness and collaboration. The new digital tools and research cultures make it possible not only to perform research more efficiently but to create new types of science and research which are more open, more global and collaborative, more creative, and closer to society. However, there are specific policy challenges relating to harnessing the full potential of open science. It would require changing traditional research systems and cultures to better appreciate and reward openness and collaboration. In order to bring most benefits, it would require the widest possible take-up by research organizations and different disciplines. It would also require recognizing and addressing possible risks and negative effects of these new ways of doing research. Therefore, there is a need to support the active development and deployment of open science for achieving most benefits for science, society, policy, and innovation.

This paper presents a vision of open science for the global research community, with proposed operational conclusions. The objective of this paper is to summarize the understanding of open science work areas and their relevance to the research community, with a concrete proposal for future action in the context of open science. The paper is divided into seven sections. After this introduction, Section II describes the open science declaration; Section III describes the scope of open science, the main aspects brought along with technologies that enable research to be more efficient, trustworthy and participative, with new interfaces to society; Section IV outlines the cyberinfrastructures; Section V describes the potential of open science for science, policy, society, and innovation, and challenges to make it happen; Section VI describes the open science practice and activities within open research that link to the recognized cyberscience aspects and perceived impacts; and Section VII concludes the paper by suggesting issues for future actions on cyberscience in open research, including a proposed approach to implement.

II. Open Science Declaration

A. Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities

The Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities of 22 October 2003 was written in English. It is one of the milestones of the Open Access movement. The wording of the English version shall prevail [4].

B. Preface

The Internet has fundamentally changed the practical and economic realities of distributing scientific knowledge and cultural heritage. For the first time ever, the Internet now offers the chance to constitute a global and interactive representation of human knowledge, including cultural heritage and the guarantee of worldwide access.

We, the undersigned, feel obliged to address the challenges of the Internet as an emerging functional medium for distributing knowledge. Obviously, these developments will be able to significantly modify the nature of scientific publishing as well as the existing system of quality assurance.

In accordance with the spirit of the Declaration of the Budapest Open Access Initiative, the ECHO Charter (European Cultural Heritage Online) and the Bethesda Statement on Open Access Publishing, we have drafted the Declaration to promote the Internet as a functional instrument for a global scientific knowledge base and human reflection and to specify measures which research policy makers, research institutions, funding agencies, libraries, archives and museums need to consider.

C. Goals

Our mission of disseminating knowledge is only half complete if the information is not made widely and readily available to society. New possibilities of knowledge dissemination not only through the classical form but also and increasingly through the open access paradigm via the Internet have to be supported. We define open access as a comprehensive source of human knowledge and cultural

heritage that has been approved by the scientific community.

In order to realize the vision of a global and accessible representation of knowledge, the future Web has to be sustainable, interactive, and transparent. Content and software tools must be openly accessible and compatible.

D.Definition of an Open Access Contribution

Establishing open access as a worthwhile procedure ideally requires the active commitment of each and every individual producer of scientific knowledge and holder of cultural heritage. Open access contributions include original scientific research results, raw data and metadata, source materials, digital representations of pictorial and graphical materials and scholarly multimedia material.

- Open access contributions must satisfy two conditions: The author(s) and right holder(s) of such contributions grant(s) to all users a free, irrevocable, worldwide, right of access to, and a license to copy, use, distribute, transmit and display the work publicly and to make and distribute derivative works, in any digital medium for any responsible purpose, subject to proper attribution of authorship (community standards, will continue to provide the mechanism for enforcement of proper attribution and responsible use of the published work, as they do now), as well as the right to make small numbers of printed copies for their personal use.
- A complete version of the work and all supplemental materials, including a copy of the permission as stated above, in an appropriate standard electronic format is deposited (and thus published) in at least one online repository using suitable technical standards (such as the Open Archive definitions) that is supported and maintained by an academic institution, scholarly society, government agency, or other well-established organization that seeks to enable open access, unrestricted distribution, inter operability, and long-term archiving.

E. Supporting the Transition to the Electronic Open Access Paradigm

Our organizations are interested in the further promotion of the new open access paradigm to gain the most benefit for science and society. Therefore, we intend to make progress by

- encouraging our researchers/grant recipients to publish their work according to the principles of the open access paradigm.
- encouraging the holders of cultural heritage to support open access by providing their resources on the Internet.
- developing means and ways to evaluate open access contributions and online-journals in order to maintain the standards of quality assurance and good scientific practice.
- advocating that open access publication be recognized in promotion and tenure evaluation.
- advocating the intrinsic merit of contributions to an open access infrastructure by software tool development, content provision, metadata creation, or the publication of individual articles.

We realize that the process of moving to open access changes the dissemination of knowledge with respect to legal and financial aspects. Our organizations aim to find solutions that support further development of the existing legal and financial frameworks in order to facilitate optimal use and access.

III. Scope of Open Science

There are several definitions relating to open science, complementing and overlapping with each other in various ways [2], [3]. The objective is to map the overall landscape of digitally enabled research and scientific practices that should be considered when discussing the contents and elements of open science. Science is defined as:

- knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method
- such knowledge or such a system of knowledge concerned with the physical world and its phenomena

In other words, science can be both considered as related to specific fields relating to studying the physical world (natural science) or as a general mode of solving problems and obtaining knowledge through the scientific method. The scientific method is defined as principles and procedures for the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypotheses. Some aspects of open science are given below:

- Open science refers to a systematic and open-minded method of acquiring knowledge about the universe through the observation, experimental investigation, testable explanations and predictions, and the theoretical explanation of phenomena.
- Open science refers to the policy of making the output of publicly funded research and academic outputs freely accessible in a digital format to society.
- Open science refers to the process of making the content and the process of producing evidence and claims decentralized, distributed, immutable, transparent and accessible to wider society.
- Attributes of open science include the searchability, accessibility, interoperability, and reusability of scientific research data.
- Open science refers to the free-of-charge publication and dissemination of scholarly research and knowledge while embracing the philosophical principles of the universality, freedom, and responsibilities of science and academic work.

Open science is about the way research is carried out, disseminated, deployed and transformed by cybertechnology. Open science is a new term which does not yet appear in publications, in policy documents, or research discussions. Adopting a new term makes it possible for the research community to define its scope in the most meaningful way to promote excellent science in the context of open science. However, it is essential that the new concept takes into account all the issues typically covered in the concepts of cyberscience.

The scope of open science reflects how the possibilities for carrying out scientific activities have evolved with the development and take-up of cybertechnology.

Open science aims to have a holistic perspective that covers considerations of all transforming aspects and reflects the need for policy efforts in order to harness the potential of cyberscience for the research community. Open science relies on the combined effects of technological development and cultural change towards collaboration and openness in research.

Open science makes scientific processes more efficient, transparent and effective by new digital tools for scientific collaboration, experiments and analysis and by making scientific knowledge more easily accessible. At the same time, open science enables the emergence of new scientific practices, disciplines, and paradigms to respond to the new challenges through globally distributed collaborations where citizens and society participate as contributors and direct beneficiaries of scientific knowledge. Open science is defined with four fundamental goals:

- Transparency in experimental methodology, observation, and collection of data
- Public availability and reusability of scientific data
- Public accessibility and transparency of scientific communication
- Using cybertechnology to facilitate scientific collaboration

Open science envisages optimal sharing of research results and tools: publications, data, software, and educational resources. It highlights three necessary aspects for realizing the vision of open science:

- Open scientific content arising from publicly funded research
- Open cyberinfrastructures for public and private research
- Open science culture

The open science culture dimension highlights the necessity to change academic assessment and reward systems to reward participation in the culture of sharing, in enabling online collaboration and reproducible open science. It is also hoped that young researchers find inspiration for making discoveries and entrepreneurship and join the ranks of scientists, engineers, and innovators in more significant numbers.

Open science is a change in science coming from the trends created by collaborative online tools and open scientific models:

- increased number of scientific authors
- increased number of scientific publications
- increased amount of data and its processing through the new availability of data from both official and unofficial sources

Open science study gathers together many aspects of the already existing aspects, but also bring forward a couple of new aspects. The cyberscience study summarizes as main trends of open science:

- Open collaboration
- Citizen science
- Open data
- Reproducibility and open code
- Open access [to publications]
- Data-intensive science
- Open innovation

Open science should take into account all the issues covered in the concepts of cyberscience as topics to be considered in policymaking. Different terms reflect the development of new possibilities to carry out scientific activities with cybertechnology, including previous issues and adding a new layer. Open science is the new growth to science and research coming from all the existing and the new, continuously developing possibilities brought by communication networks, digital availability of scientific content and new activities and interactions enabled by technologies.

The various concepts reviewed above, highlight three main perspectives and important constituents of open science:

- Cybertechnology - enabled methods have changed the way scientific discoveries can take place. Communication, computing, and data storage infrastructures enable data- and computing-intensive research tasks which were not possible before, and new means to generate and explore data which enable scientific discovery. Specific scientific software enables new field-specific research methods, and new platforms provide opportunities to manage and generate large collaborations, also through social media. Emerging tools support the generation of new scientific metrics and reputation systems as meta-level support for scientific processes.
- The openness of research has become a recognized objective in enhancing the value of scientific knowledge by ensuring its accessibility for all through online media, which also contributes to the quality, transparency, and reproducibility of research results. This includes open, immediate and free access to scientific papers, underlying research data, as well as the software and models used for results generation. Later trends highlight opening up also research process materials as knowledge resources for further scientific activities, through publishing intermediate results, lab books, and personal research knowledge and work resources.
- Collaboration in research has changed dramatically through communication networks and social media, enabling entirely new scales of scientific collaboration. Remote collaboration between researchers and research organizations is a necessary part of all scientific activities, increasing interdisciplinary research projects with global teams. Furthermore, scientific collaborations are developing towards large scale projects which enable open participation of any interested actors, harnessing the collective intelligence of both professional and amateur researchers. The openness of research processes enables dynamically created collaborations in solving specific scientific tasks and online communities of practice support and link research actors also outside specific research tasks.

Two important aspects underlying and following this concept are:

- Open science is solidly based on cyberinfrastructures, for

i) developing and sharing specific cybertechnology tools for scientific tasks; ii) providing seamless online access to scientific resources, including publications and data; iii) providing and developing platforms and tools to enable large scale collaborations without the need for physical proximity. Cyberinfrastructures play an essential role in implementing and widening open science policies and practices and need open science work for driving the scientific development enabled by the technologies.

- The "Openness of research" and "Collaboration in research" dimensions are making it possible to involve society and citizens in scientific research and scientific discussions in new ways. Citizen participation can be a part of global scientific initiatives, which can also be initiated by the citizens and amateur scientists themselves. In this way, new ways of engaging citizens into scientific processes is becoming a new tool and method for research itself. Furthermore, opening access to and better communicating scientific knowledge is important not only for scientists but also enables citizens to be better informed of scientific advances and thereby more confident in science-based decision making. Therefore, the interaction of science and society should be considered as an important dimension of open science.

A. Open Methods for Research

Cybertechnology has changed the way scientific discoveries can take place. Communication, computing, and data storage infrastructures enable new data - and computing-intensive research tasks and new tools enable virtual experiments which were not possible before.

- Data is being generated in large scale through images, sensors, simulations, logging of online human activities and all this can be stored for later processing, enabling new research, e.g. in social sciences and human behavior.
- Combining data from various sources and new types of data exploration and analysis tools enable discoveries and recognizing new research questions, e.g., in biodiversity and genetic research.
- Efficient computing resources, whether high-performance computers, computing grids and also cloud computing resources enable asking complex questions and developing models which require computing power for their testing and application.
- Virtual experiments in silico, remote access to specific equipment, and simulation environments enable experimentation-based research in new areas and for a wider audience.

B. Open Access to Research Results and Processes

Open access to research results through digital means enables faster and broader diffusion of scientific knowledge. The philosophy of openness in cyberscience is even more extensive, aiming at opening the whole research process and results for peers and public, through digital media and collaboration efforts. Open access to research publications in open access journals or article repositories makes them freely available for anyone while new tools for citations, metadata, and interoperability of repositories improve the discoverability of scientific knowledge on a new scale. Micropublications of specific pieces of scientific information make scientific knowledge accessible in new ways, through modern devices.

- Making research data underlying the research publications available enables reproducibility of the research by others, for verifying the results and reusing the data for new research purposes.
- Transparency of research improves through publishing experiments and research results which would not usually be published in traditional scientific journals, e.g., the results of clinical trials experiments which did not prove the expected hypothesis.
- New technological solutions combined with open access to research resources enable citations and cross-references between publications, data, and authors in a way that enables new traceability of research evidence flows and creation of new connections between research topics and actors. These also enable new means for evaluating the value of science through following the reuse of the scientific work, replacing traditional publisher-based scientific value metrics by research-oriented ones.
- Opening up research resources facilitates scrutiny and feedback by peers and even the public already during the research process, enabling the research approach to be refined and improving quality through additional contributions.

C. Collaboration in Research

Possibilities in research collaboration have changed dramatically through communication networks and social media, enabling entirely new scales of scientific collaboration. Virtual collaboration between researchers and research organizations is a necessary part of all scientific activities – the grand challenges of today cannot be solved by any one scientist or single discipline alone.

- Setting up collaboration projects between researchers is supported through tools and online platforms which enable sharing data, research tools, project communication and collaborative knowledge creation in virtual research communities of global scale.
- Digital tools and platforms enable setting up large scale collaborations which can harness the collective intelligence of any interested actors.
- Embedding social media and social networking tools into research processes enables dynamic spontaneously arising collaborations in solving or addressing specific tasks.
- Informal collaborations are emerging in virtual communities of practice and through sharing personal knowledge resources which support knowledge and expertise flows in a networked system also outside specific research tasks for researcher networking.

D. Interaction with Society

Engaging citizens and society are possible in entirely new ways, because of the digital tools and platforms for research and

increasing attitude towards openness. Citizens can and are interested in contributing to science both with their intellectual effort, observations and with their cyber tools and resources, which creates new relationships between science and society. Specific initiatives and networks make possible crowdsourcing of computing resources through user-friendly interfaces for the public, thereby enabling anyone to decide to easily contribute to science through digital resources.

- Engaging citizens in data gathering activities improves coverage of research data, e.g. from more geographic areas, with more extensive samples or longer-term systematic data collection that would be possible by research groups alone. Also, traditional forms of citizen science, are made possible in entirely new ways through online global communications.
- Several scientific initiatives are organized as collaborative initiatives that enable participation of citizens, without in-depth scientific knowledge, but with interest in contributing to joint activities. Citizens can contribute through their intellectual effort, e.g., in the form of image recognition, local context knowledge, or other intellectual efforts with an essential additional contribution to professional researchers' work.
- Opening research results and processes through digital media and involving citizens as active participants in research processes rather than objects of research also promote developing ethical and responsible research models where citizens and society both contribute to the results and shape the research process through proposing research ideas and comments on the results.

E. Benefits of Open Science

Though the benefits of open science are numerous, some of the benefits are listed below:

- Reducing duplication costs in collecting, creating, transferring and reusing data and scientific material; allowing more research from the same data; and multiplying opportunities for domestic and global participation in the research process.
- The greater scrutiny offered by open science allows a more accurate verification of research results.
- Increased access to research results can foster spillovers and extra benefits to researchers, not only to scientific systems, but also innovation systems broadly.
- Open science also allows the closer involvement and participation of citizens from across the globe.

F. Responsible Open Peer Review

Responsible open peer review ensures that scholarly research meets accepted disciplinary standards and ensures the dissemination of only relevant findings, free from bias, unwarranted claims, and unacceptable interpretations.

G. Principles of Responsible Peer Review

1. Honesty in all aspects of research
2. Accountability in the conduct of research
3. Professional courtesy and fairness in working with others
4. Good stewardship of research on behalf of others

Responsibilities. The following responsibilities of open peer review apply to scholarly researchers at all stages of peer review:

- Fairness
- Transparency
- Independence
- Appropriateness and balance
- Participation
- Confidentiality
- Impartiality
- Timeliness
- Quality and excellence
- Professionalism
- Duty to report

H. Open Science Aspects

As seen above, all the open science aspects support each other and contribute to the change of scientific practices. Implementing open science strongly relies on cyberinfrastructure, especially for i) developing and sharing specific digital tools for scientific tasks; ii) providing seamless online access to scientific resources, including publications and data; iii) providing and developing platforms and tools to enable large scale collaboration without the need for physical proximity. Complementarily, open science policies ensure the full and effective use of cyberinfrastructures.

IV. Cyber Infrastructures

Cyberinfrastructures address the needs of researchers for digital services concerning networking, computing and data management [1]. Cyberinfrastructures foster the emergence of open science, i.e., new working methods based on the shared use of cybertechnology tools and resources across different disciplines and technology domains as well as sharing of results and an open way of working together. Furthermore, cyberinfrastructures enable and support the circulation of knowledge in global online and therefore constitute an essential building block for the global research area which is a unified area open to the world, in which scientific knowledge, technology, and researchers circulate freely.

Cyberinfrastructure combines supercomputing capability with high-speed connectivity and leading-edge data and software services for science, industry and the public sector. The global research area stimulates open science and innovation by enabling researchers to access and re-use the vast amounts of scientific data. The global research area fully unlocks the value of big data and fosters scientific and technological innovation while helping achieve the objectives of the digital open science strategy.

The cyberinfrastructure expands, with emphasis on further integration and finding synergies and reusing existing infrastructures. Sustainability and innovation, as well as tackling the big data challenge are the focus areas. Cyberinfrastructures are key to the future development of research infrastructures as activities go increasingly "online"

and produce vast amounts of data. Projects to be included are already at the application stage to assess their e-needs, and many relate to supporting cyberinfrastructures. Cyberinfrastructures also contribute to the availability of high-speed broadband Internet and access to digital service infrastructures as the building blocks allowing communication, services, and business to grow - allowing components such as cloud computing, the "internet of things" or big data applications to exploit their full potential.

V. Potential and Challenges for Open Science

Openness and sharing of information are fundamental to the progress of science and to the effective functioning of the scholarly research. The advent of scientific journals helped researchers to communicate across time and space, using the technologies to generate reliable knowledge more quickly and efficiently. Harnessing current stunning, ongoing advances in information technologies, the global scholarly research and its stakeholders are moving toward a new open science ecosystem. Open science aims to ensure the free availability and usability of scholarly publications, the data that result from scholarly research, and the methodologies, including code or algorithms, that were used to generate those data. Open science is aimed at overcoming barriers and moving toward open science as the default approach across the scholarly research.

The changes in digitally facilitated scientific processes are already taking place to intellectual property rights and privacy concerns relating to the new models of openness and collaboration. Open science action is necessary for supporting effective take-up of new research methods, tackling common challenges in the transformation of research organizations and scientific processes and ensuring that the concerns of digital citizens, as well as the concerns of innovative industries, are being addressed. The potential areas of impacts of open science practices and main challenges for this potential to become a reality are summarized.

A. Potential for Open Science

Transformation of science. Cyberscience is about technology-enabled trends in society and the economy, which promote the transformation of the scientific system, democratizing access to research and creating new linkages between science, society, policy, and innovation.

- Hierarchically organized and specialized scientific fields become more connected with each other and with application areas. This creates new multidisciplinary and interdisciplinary research, leading to the emergence of new disciplines and connections to study emerging research questions and topics.
- Scientific practices become more efficient and trustworthy through openness that enables verifiability and transparency of research results, maintenance of proof linkages and new forms of incremental collaboration. Science quality metrics of the future can highlight replicability, verifiability, and reuse of research results instead of publication channels.
- The old restricted and "elite" approach of science expands to a more egalitarian view of research, as scientific methods, processes, and knowledge becomes more accessible to anyone through readily available tools. Learning about science becomes easier, and science courses can include observation and participation in scientific communities allowing future researchers to get familiar with open science practices.
- The relationship between science, society, and policy develops towards a new symbiosis and a topic of scientific study as such internet science. Through access to scientific information and processes, citizens are aware of the potential and limits of scientific knowledge creation and can participate in studying and monitoring issues relevant to them.

Open science for society. Opening access to research results and processes, and increased usage of social media for research purposes make it easier for anyone to access scientific knowledge and processes. This has the potential to improve the scientific literacy of citizens in general and improve interest and knowledge of young people in science and technology, despite their age, educational background, or socio-economic status. Participative, open science approaches contribute to education, inclusion, and employment, by supporting lifelong learning of several key competencies, especially Science and technology, digital competence, social and civic competence, sense of initiative and entrepreneurship. Moreover, open science has potential to re-attract young people and citizens at risk of exclusion into activities which are personally meaningful to them, contribute to their learning and thereby inclusion in the information society and economy.

Open science for policy. Various aspects of open science improve its trustworthiness and availability of science for policymaking. Furthermore, and more importantly, empowering citizens to access, understand and participate in scientific processes enhances their acceptance of policies which are based on scientific evidence and which enable citizen participation in their development and monitoring. Embracing the open science approach to policy-making enables creating collaborative initiatives where policymakers collaborate with scientists and citizens in searching, developing and comparing options to solve global challenges. Involving citizens in the scientific development underpinning policy decisions also encourages their ownership and engagement in implementing social changes and policies for societal benefit.

Open science for innovation. New research tools and methods together with openness, collaboration and societal involvement in research provide research results more readily available for industry and SMEs. Furthermore, they provide models which can also be used for commercial innovation or collaborative product and service development based on user innovations and contributions. Improved access to research results can be a driving force for innovation especially in developing regions and countries, but also participation in collaborative research applying Open science philosophy can also provide benefits for commercial actors. Open science enables efficient collaboration with a large group of

collaborators from various backgrounds, generating ideas which can be developed into commercial products although basic research is done in the public domain.

B. Challenges for Open Science

Although there are many potential benefits of open science approaches, and successful examples of their application, a transformation is not taking place equally in all organizations and disciplines, for various reasons.

- In some disciplines, the benefits of open science practices are more evident than in others. Some fields are already advanced (e.g., physical sciences, life sciences) while others are lagging (e.g., social sciences). Further analysis of disciplinary dynamics and the specific benefits open science aspects could provide them is needed.
- Openness of research publications is a recognized objective but often difficult to implement by researchers, who do not necessarily have the freedom to select the journals in which their results are published. Their performance for career development may be evaluated based on metrics contrary to the objectives of openness.
- Researchers may not be convinced of the benefits of opening results and processes with only a vague view of future benefits and no guarantees of reciprocity. Furthermore, there is a tension in the objectives of publishing new results first against collaborating and opening ongoing research processes, especially when concerning innovation and product development for business.

It is challenging to develop open and collaborative scientific initiatives where various types of actors, including citizens, can participate. The initiative should at the same time provide personal value for the different types of participants who are investing their time and effort and ensure the scientific value of the results. Therefore, careful planning of quality assurance aspects, scientific knowledge and skills development, and motivational elements is crucial for creating successful and sustainable open research collaborations. These challenges play a significant role in hindering the take-up of new scientific practices in some disciplines, organizations and geographical areas. As described earlier, open science is not only the take-up of technologies but also a change in scientific culture. This would require changes in the institutional practices in the research institutions and exploration of how open innovation and research collaboration practices can improve competitive positions in industry. This cultural change will not take place if there are no good examples, leaders and perceived benefits. Therefore, considering these issues must be included in the open science philosophy for supporting open science.

C. Benefits and Motivation

The scholarly research has already made significant progress toward open science and is realizing a number of benefits:

- Rigor and reliability
- Ability to address new question
- Faster and more inclusive dissemination of knowledge
- Broader participation in research
- Effective use of resources
- Improved performance of research tasks
- Open publication for public benefit

D. Barriers and Challenges

Despite the significant progress made toward creating an open science ecosystem, science is not completely open. Several barriers and challenges remain:

- Costs and infrastructure
- Structure of scholarly communications
- Lack of supportive culture, incentives and training
- Privacy, security, and proprietary barriers to sharing
- Disciplinary differences

Open science stands at an important inflection point. The ability to automate the process of searching and analyzing linked articles and data can reveal patterns that would escape human perception, making the process of generating and testing hypotheses faster and more efficient. Cybertechnology will have maximum impact when used within an open science ecosystem that spans disciplinary boundaries.

E. Open Science Design

The researcher is at the center of the concept of open science design which is defined as a set of principles and practices that fosters openness throughout the entire research life cycle. At each stage of the research process, the researcher both contributes to open science and takes advantage of the open science practices of other members of the research community:

- Provocation
- Ideation
- Knowledge generation
- Validation
- Dissemination
- Preservation

The vision of open science design suggests that all phases of the research process provide opportunities for assessing and improving the reliability and efficacy of scientific research.

F. Open Science Progress

Achieving open science will require persistent, coordinated actions on the part of scholarly research stakeholders with key findings, recommendations, and implementation actions:

- Building a supportive culture
- Training for open science design
- Ensuring long-term preservation and stewardship
- Facilitating data discovery, reuse, and reproducibility
- Developing new approaches to fostering open science design

VI. Open Science in Practice

Some of the aspects and objectives of open science are currently included in research activities and future perspectives, and visible in the open science publications. Open science activities are aimed at supporting the development of open science practices, addressing related challenges and engagement of stakeholders through policies, R&D projects,

and support actions. Different types of activities include, for example:

- Research developing and piloting new approaches
- Research supporting research tools and cyberinfrastructures development and provision
- Research supporting understanding of open science and related challenges
- Policies on promoting and enhancing specific aspects relating to open science (open access, open data), or addressing related challenges, (IPR, privacy, digital literacy)
- Research to support engaging citizens in research and learning about science
- Platforms and initiatives to support stakeholder interaction on policy and science development

A. Objects of Enquiry

Open science work issues for research relate to all the main aspects (new research methods, access to research results, collaboration, and interaction with society) in a cross-cutting way. Open science relates to several policy areas, where technologies and networking can be applied. Some of its aspects are explicitly mentioned (especially open access) in the current policy framework, and others contribute indirectly to the higher level goals and objectives.

Open science action is needed to support national policies and actors with cybertechnology - related development by:

Developing tools and models for open science. Research on various work programs support development of open science tools and practices with applicability to various research topics:

- Experimental approaches and research tools, e.g. autonomous software, large scale experiments
- Collective awareness platform development
- Research collaboration models and tools for citizen engagement
- Data infrastructures and essential supporting elements such as metadata, citation models, author and object identifiers

Supporting capacity for open science. Research and other activities aim at developing and supporting the capacity of stakeholders to engage in open science practices:

- Pooling and development of main cyberinfrastructures for research services and research repositories, including publications and data
- Transnational access to digital research services and collaboration opportunities for all researchers, whether public, private, or amateurs
- Awareness and skills for open science among existing and potential future researchers, research funders, research infrastructure actors
- Research and innovation support in service-oriented architectures, digital computing strategy

Addressing risks and challenges. Several policy and support activities aim to address the uncertainties, risks and challenges to harnessing the potential of open science:

- Improving the theoretical understanding of open science including social sciences aspects
- Monitoring open science status development and barriers among stakeholders, maintain a dialogue in order to take into account their concerns into account
- Policy leadership and support for transformation from closed research models to openness through open access policies, new incentive systems, science metrics
- Addressing needs to revise IPR rules for enabling research on digital research results (e.g. data mining), licenses relating to research data sharing and publication

B. Stakeholders

The stakeholders for open science are the groups concerned by open science approaches.

Research actors, including research organizations, research funding organizations, national infrastructure providing organizations, learned societies, networks of academies, disciplinary and interdisciplinary research communities and the emerging informal researcher communities of practice.

Policymakers, including national R&I policies, all science-based policy fields at the national and global level, with the potential for open science support for policymaking.

Industry, including publishing industry, commercial research infrastructure, and service providers, research performing industry (including SMEs), cybertechnology industry.

Society, including NGOs, citizens (highly/lowly educated, employed/unemployed – i.e., both those who are well-off and those at risk of exclusion), young people (at schools and outside), public intermediaries (institutions for education, health, employment).

C. Areas of Impact

Open science is perceived to have an impact on the overall scientific system and its links to society, policy and innovation. In addition to the activities mentioned above, there are specific activities targeted to supporting these impacts, again through both policies and research projects.

1. Applying and Experimenting Open Science Approaches in Different Disciplines

- Research community-driven development of virtual collaboration platform of specific topics and disciplines
- Large scale pilots on experimentally-driven research and open research collaborations in biomedical and clinical research
- Discipline specific experiments such as robotic DNA experiments in biomedical sciences, virtual physiological human

2. Bridging Science and Policy

- Global systems science approach to policy making
- Multistakeholder dialogue platform for future vision development
- Engaging social change by improving the collective awareness of citizens

3. Bridging Science and Society

- Improving the awareness and trust of citizens in science through supporting citizen science development

- Improving science visibility in the media
- Linking scientific communities into learning science at schools and universities through cybertechnology

4. Bridging Science and Innovation

- Industry participation in research project pilots on open access models
- Harmonizing acceptable usage policies for research collaboration on shared cybertechnology platforms and infrastructures

VII. Conclusions

The changes in digitally-facilitated scientific processes are already taking place to IPR and privacy concerns. Open science action is necessary for supporting effective take-up of new research methods, tackling common challenges in the transformation of research organizations and scientific processes and ensuring that the concerns of digital citizens, as well as the concerns of innovative industries, are being addressed.

Open science activities are addressing several open science aspects already. However, further work is needed, and establishing collaborations with other actors and services is essential for achieving the most significant impact.

A. Broad Objectives for Open Science Activities

Recognize, support and upscale success in most promising areas. It is important to explore and improve understanding of where open science approaches benefit the topic and where they may not be applicable. The areas of most potential benefit should be prioritized in project and policy support activities. Attention should be directed at recognizing successful research groups and small initiatives to increase scale and to complement large-scale actions.

Deploy open science for addressing current challenges. Necessity drives effort and innovation. People are in need of jobs, education, and a sustainable lifestyle. Open science should be concerned with finding answers to these questions in efficient, effective and participative ways.

Consider possible risks and negative impacts of open science. Although cybertechnology - based models and simulations offer new approaches to science, it is important not to forget observations as the basis of science, e.g., in social and biospheric sciences. A critical perspective must be maintained in supporting cyberscience development and expansion, and to keep eyes open for the emergence of other promising paradigms. Ensure connections and considerations for all stakeholders. Mapping of current activities suggests that there may be stronger links for academic research stakeholders than other stakeholder groups. It is important to ensure that research has good connections and linkages to all stakeholders, including society and industry, and that their considerations are included in the open science support activities. Collaboration with other relevant digital services must be established for ensuring good coordination of activities.

B. Proposed Approach to Open Science

This paper has recognized open science as an issue which needs both policy and operational dimensions in the work of open science research. In order to support open science effectively and in a timely manner for people, these must be integrated into open science research.

Open science research should address the 'objects of inquiry' recognized for advancing open science, and mainstream open science by integrating it into the rules and guidelines for open science research. In order to achieve the most impact of these measures, they must be accompanied with support actions for effective best practice sharing and dissemination of the projects' results.

C. Addressing the Objects of Enquiry

Open science research must ensure that the recognized objects of inquiry for open science are addressed in the respective parts of the open science work programs as well as in the overall approach. This requires effective coordination within open science research and analysis of the relationships between the different work program areas and their relevance to open science. Concretely, several open science work programs contribute to developing open science on different levels:

- Technologies and components for data gathering and networked systems
- Models, methods and tools for future research and information processing
- Platforms and infrastructures which can support collaborative research
- Innovations for open science, developing understanding of the related challenges

The relevant open science work programs definitions should be open to proposals with specific contributions to open science, which should be effectively disseminated and shared among other projects and research stakeholders. In addition to developing these specific contributions, all open science projects should apply open science as their working methods when relevant, and thereby contribute to developing best practices, uptake, and skills for open science, and to engage different groups of stakeholders, including industry.

D. Mainstreaming Open Science

In order to support researchers' awareness of open science values and benefits, the research grant process should systematically encourage and embrace open science. This could be supported through requirements included in the grant agreement, evaluation criteria for projects, guiding documents for the proposers, as well as through supporting cybertechnology tools and cyberinfrastructures.

The objectives in all open science work programs should be to encourage research projects to implement open science approaches (when appropriate):

- to systematically make use of and contribute to cyberinfrastructures;
- to embrace open and collaborative research approaches, by sharing research data, tools and results and collaborating

with the broader research community, i.e., including scientific actors outside the project partner organizations;
- to embrace cybertechnology tools as an interface between the scientific community and its stakeholders in policy and society, explore citizen participation and invest in dissemination and educational activities;
- to become aware of the open science-related policies (e.g., open access, open data) and challenges (e.g., comprehensive data management plans), implement them within the project activities and promote them in institutions also outside the project;
- to report both success stories and specific challenges on embracing open science practices by individuals, organizations and in different disciplines.

This mainstreaming of open science should be implemented through following operational means:

1. All Open Science Grant Agreements Should Include:

- A mandatory clause on open access to publications, and an obligation to ensure that all publications produced are linked to the open portal
- Commitment to appropriate digital research data management, with considerations for its preservation, sharing and dissemination
- Option for a special clause on open data pilot

2. The Open Science Research Project Proposals for All Calls Would Be Required to Include in Their Submission:

- Where datasets are produced, a data management outline, to describe the initial planning for managing, storing and sharing digital research data and metadata.
- Where appropriate, a description of the impact of the project on open science in the specific field, including the development of scientific open collaboration, future oriented scientific skills, science-society interaction and on uptake of cyberinfrastructures.

3. In the Project Implementation, the Open Science Work Would Ensure:

- Awareness of the consortium of open science and its possible benefits for the project.
- Inclusion of the digital research data management plan in the project deliverables, with regular updates.
- Monitoring and reporting open science aspects of the project, such as: research participation by the broader research community, citizen participation to the scientific activities, dissemination to society, implementation of educational activities, open access publications, open access datasets made available with metadata, open code and algorithms made available by the project and the (re)use of these by others.

Open science represents a new approach to the scientific process: shifting from the standard practices of publishing research results in scientific publications towards sharing and using all available knowledge at an earlier stage in the research process. Open science originates with the premise that universal scientific knowledge is a product of a collective scholarly and social collaboration involving all stakeholders and knowledge belongs to the global society. Scientific outputs generated by public research are a public good that should be available to all at no cost and without barriers or restrictions. The broader public should have access to publicly-funded research and its benefits provides an additional strong rationale for open science. In the case of publicly-funded research, the ultimate sponsor is the citizen. The public benefits from open science as new knowledge is utilized more rapidly to improve health, protect environmental quality, and deliver new products and services.

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