A collection of services to perform cutting-edge research in Europe and beyond

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The European Open Science Cloud (EOSC) initiative aims at supporting more than 1.7 million researchers and fostering interdisciplinary research in Europe. To understand better, what the research community needs, the EOSCSecretariat partner TU Wien organized workshops, consultations and an Exploration Series. The objectives were to collect visions, needs and requirements for (future) research environments as well as initiatives and services that support cutting-edge research.

Two workshops and a discussion round with Science Europe were held in early 2020. The first workshop targeted researchers with different scientific backgrounds, although the focus was on natural and technical sciences. Experts on open science and members of universities were invited to the second one. In both cases, the main objective was to collect actual needs of researchers (and their institutions) to perform cutting-edge research. The first workshop was summarized in [2, 4], the second one in [1, 4], while [4] gives an overview of the discussion round with Science Europe.

Online consultations focussing on visions, needs and requirements in the healthcare domain took place in June and July 2020. A report and key takeaway messages were published soon after [3, 11].

An Exploration Series that aimed at projecting current developments of technology and society into the future, deriving needs and requirements for research environments was implemented. It explored visions, needs and requirements of researchers to perform effective and efficient top-level research, looking at opportunities and risks in the evolving research landscape in a series of interviews with researchers ranging from Marie Curie Fellows via ERC Grantees to a Nobel Laureate [6, 7, 10, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 30, 31, 32]. Interviews with Scientists-turned-prominent-Sci-Fi-writers revealed perspectives to complement purely scientific views and projections, specifically [8, 13, 25, 27, 28, 29]. The Exploration Series resulted in two reports [5, 9] and key takeaway messages [12, 26].

This document integrates and summarizes the results from the previously described activities and their associated reports and provides a succinct summary, listing all services collected during these activities. They have been divided into eight categories, which in alphabetical order are:

1. Competition / Collaboration
2. Data
3. Education & Science Communication
4. Interdisciplinarity & Focus
5. Systems
6. Monopolies & RoP
7. Support Services
8. Trust Issues in Research Systems

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1 Competition / Collaboration

Initiatives and Services	Description
1.1 Initiatives to prevent artificial scarcity	Being in a better position increases the chances of getting funds, access to data, or any other seemingly scarce resource. This leads to competition in what is essentially a zero-sum game for scarce resources. That, in return, is going to cripple any attempts to build any kind of improved research environment, unless research systems can somehow be safeguarded against exploitation such as battling for resources and (in-)fighting for positions.
1.2 Initiatives and services that help build bridges and connect researchers and their institutions across geographical borders on local / institutional level	Even though (scientific) challenges extend across borders the global / international profile of research and (administrative) cultures of institutions appear to be disconnected on a local level. Helpdesks or ways of bringing together people to share experiences and best practises are first steps to improve local situations. Additionally, the mobility of researchers and research staff should be encouraged and supported on a broader scale by embedding research visits as part of the EOSC culture of infrastructure use.
1.3 Initiatives to support research as collaborative effort and team science	(In-)Fighting for positions due to too much emphasis on competition are fuelled by over-crowded research environments and reward mechanisms: Individuals are singled out based on their publications, citation counts, or grants. This is hindering research as a collaborative effort that is societally beneficial and that maximizes knowledge. To improve the current situation, rewards should be given to specific communities, or teams that have created meaningful insights instead of selecting individuals from such teams. That might also enhance and enable team science.
1.4 Services and funding mechanisms to facilitate research collaborations within small(er) groups	Research collaborations and research consortia facilitate the pooling of resources in order to achieve common goals. There are, however, limits to this kind of joint efforts: if consortia are too big, involving and synchronizing all key players efficiently is not possible. Thus, research collaborations within smaller groups must be facilitated and funded.

2 Data

Initiatives and Services	Description
2.1 Services to help with checking and verifying data quality	The trustworthiness of data has to be ensured by all means. However, trust requires understanding where data comes from. Consequently, there needs to be a transparent framework to understand the data. In general, provenance and data quality, have to be checked or, at the very least, be checkable, ideally automatically by machines. EOSC shall thus offer services that allow for the documentation of how data is gathered to make (meta) data more searchable, findable and trackable and to support many different formats. Examples are services to enable the automatic recording of provenance metadata for data, computation, and processes, services for data capturing (that can even include cryptographic verification of data like cryptographic signatures on the metadata on the data being processed), and services for trusted validation processes. The latter is crucial because researchers will refrain from using datasets that they do not trust. Thus, EOSC must find ways to guarantee the quality of data.
2.2 Services for secured and monitored data visiting	Such services need to support the negotiation of access to sensitive data automatically. Trust analysis algorithms need to be established for data, compute environments, researchers, code and results. Infrastructures need to be provided that allow research on highly sensitive data, while preventing data leakage.

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2.3 Establish civic data cooperatives	In order to derive increasing societal benefits from the use of data, data has to be taken away from those with an immediate (economic) interest in data (such as research institutions and health systems) and put into a neutral trusted body that only benefits from data being used. Thus, citizens are needed to act as their own hub and as a trusted third party. Such civic data cooperatives are not about radical changes but about developing a culture that starts to think more as a group or as a system.
2.4 Services to support reproducibility	Access to primary data is crucial in order to reproduce research results. Thus, the means to access primary data, code, compute environments and services that support reproducibility need to be provided.
2.5 Services to assist in making data FAIR	Applying FAIR principles to data is central for making research (funding) more efficient and sustainable as redundancies can be avoided. Therefore, EOSC should offer services that help make data FAIR such as access protocols, ontologies, advanced search mechanisms, etc., taking the burden off the shoulders of the researchers.

3 Education & Science Communication

Initiatives and Services	**Description**
3.1 Introduce data literacy, digital literacy and education around privacy concepts into school curricula.	People need to have competences in reading data, evaluating data, classify information correctly, or assess whether data is suitable for addressing a specific task. Thus, data literacy basics should be anchored in curricula early on and form an integral part of EOSC training at all levels of education.
3.2 Initiatives to foster scientific thinking	Present science as an investigative process, convey scientific reasoning, teach how to make connections between pieces of knowledge and bring the appreciation of complexity and uncertainty closer to pupils and students.
3.3 Guidelines and Training to increase the number of researchers who know how to make data FAIR and how to annotate data properly	Guidelines and trainings to increase the number of researchers who understand the relevance of making data FAIR and who know what it takes to do FAIR Science and how to annotate data properly, are essential to further optimize the reuse of data (with a focus on, ultimately, automating many of the steps, c.f. 2.5).
3.4 Services for research promotion to increase the impact of science in society	EOSC is not only about data, or data infrastructures. It is also about laying the foundations for the production of knowledge and knowledge transfer (teaching, mentoring, and educating). Thus, services to promote science and increase its impact in society through communicating science from the very technical and difficult to grasp down to a level where the average person is able to understand it are needed. Additionally, research institutions as well as researchers have to take responsibility for establishing a dialogue between the broader public and the world of science, supported by professional services to help them achieve this (non core-research) goal.
3.5 Services for knowledge brokering	Such services facilitate two-way or multiway exchange of information, bridge gaps between knowledge producers and knowledge users and build connections between different audiences. Thus, they also promote research output, increase research impact in society and steer research towards a more comprehensive understanding of a problem.
3.6 Services that enable machine actionable scholarly knowledge sharing	Machines need to be able to search for, find and act upon scholarly knowledge across all types of research outputs. Examples include concepts such as Nano-publications (nanopub.org) and infrastructures such as Open Research

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	Knowledge Graph (orkg.org), or services to find data by properties (e.g. distributions) or code segments.
3.7 Services for virtual (team) meetings	Virtual environment services or virtual reality solutions for meetings, supporting sophisticated interaction between researchers shall be developed, in order to overcome the current barriers of video conferencing and remote interaction.
3.8 Services for ontology mapping	(Semi-) Automated services that provide mappings between and integration of ontologies across domains, as well as tracking their evolution over time are needed to support efficient and effective communication and collaboration both for humans and machines.
3.9 Services for horizontal translation & communication adaptation	Currently, science communication rests predominantly on the shoulders of researchers. Those, however, are predominantly trained in peer-to-peer communication of science. Thus, translation services to communicate research outputs to policy makers, to the public and across disciplines, e.g. services for automatic metaphor translation. Services to translate scientific concepts and explanations for different levels of expertise within a discipline, e.g. services for math translation explaining some mathematical concepts for specific research questions.

4 Interdisciplinarity & Focus

Initiatives and Services	Description
4.1 Services that identify and collect research questions and topics that are interdisciplinary in nature	The focus on interdisciplinarity for the sake of interdisciplinarity does not support cutting-edge research. Interdisciplinary research tends to be successful whenever research topics and questions emerge that cannot be tackled by one discipline alone. Thus, services that identify and collect research questions and topics that are interdisciplinary in nature might help to identify and address such challenges.
4.2 Incentives for and recognition of highly focused studies	Drawing conclusions from big data does not necessarily enhance science or scientific output, because big data also comes with higher complexity. That might lead to a higher false discovery rate. Thus, while having access to big data is useful it is also crucial to have support in EOSC to conduct highly focused studies.

5 Systems

Initiatives and Services	Description
5.1 Initiatives to involve stakeholders in an on-going dialogue on the development of research environments	The world is constantly changing. Thus, the needs of researchers for research environments may change over time. Consequently, the EOSC as part of a global (future) research environment needs to be constantly aware of its stakeholders' needs to elicit new requirements and to ensure that the services offered remain cutting-edge. Developments of research environments (including the provision of services) therefore have to be accompanied by ongoing dialogues involving all stakeholders.
5.2 Services and organizational incentives to connect various (health) systems	Connecting various (health) systems with each other is key in order to understand such systems better because it allows bringing in different communities and considering socio-economic deprivation. This is difficult to achieve because it requires organized efforts of society. National trusted nodes, however, are a good starting point to connect different health systems by working on specific topics, aligning with each other, flexibly agreeing on e.g. protocols on the technical, legal and trust level and – by doing so – enabling an organic growth of research institutions, health provider networks.

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6 Monopolies & RoP

Initiatives and Services	Description
6.1 Initiatives to implement and support strategies to de-monopolize and pluralise policy spaces	There is a trend towards dominance of a few players establishing quasi monopolies or oligopolies serving their own (legitimate) interests, which do not necessarily match the interests of society. This results in mistrust of society in new technologies, developments and their underlying research. Counter strategies may include the reduction of barriers to access to infrastructures and services, the prohibition of mergers, re-considering the dominance of scientific publishing houses or other industries that dominate certain fields of R&D, the implementation of acts of manipulation as a feature of any future system, and the rethinking the constant striving for optimisation. The latter leaves systems vulnerable as they may have only one single point of failure. A trade-off between a resilient system and a highly optimized one needs to be taken into consideration when building research environments.
6.2 Initiatives to change publication systems in order to increase benefits for society and the increase of knowledge	Softening the current publication system might increase knowledge as well as benefits for society. That could be achieved by a lobby for legislation that curtails publishers of scientific journals in their profiteering, enforce the opening of publicly funded research results along with data, or base funding not solemnly on publication lists but also on science communication and social outreach. Additionally, EOSC shall offer publication services for papers, code and data to surpass traditional journals.
6.3 Rules and services to counteract data colonialism	Counteracting data colonialism is a political imperative. Potential solutions must involve society and need to be based on trust and mutual aid. Thus, it is crucial to have the data work for residents and do better for society with what is already there. Implementing consortia of actions and protocols, impeding vendor dominance, establishing basic GDPR rights to data portability, duties of transparency and cooperation for each participant, or relying on civic data cooperatives are ways of building up trust and increase access to (health care) data with an active consent of citizens in the long term.
6.4 Rules, protocols and verification mechanisms to avoid vendor lock-in	It is crucial to avoid vendor lock-in and vendor dominance, because data intensive systems must be able to interact. Thus, interoperability must be enforced: Tool chaining that allows for flexible processing workflows, or interoperability sessions can counteract vendor lock-in. Such interoperability sessions can be scheduled on a regular basis (e.g. biennially) for three to five working days and oblige computing vendors to get together to demonstrate tool chaining the lossless exchange of data and prove their interoperability. The growth from a bottom-up network in combination with basic GDPR rights to data portability and the duty of transparency and cooperation for each participant support the interaction of systems.
6.5 Rules to avoid quasi monopolies and dominance	Control of market share and ensuring that no contributor of services becomes dominant in size or too-big-to-fail is crucial. In combination with mechanisms countering lock-in into specific services or providers, the EOSC should ensure resilience and flexibility by guaranteeing that a diverse set of actors are providing services in a transparent and cooperative manner.
6.6 Services to promote and enable Open Science	Open Science facilitates access to scientific data for professionals and the larger public. It is a positive (democratizing) development as it helps with access to resources anytime and anywhere following transparent rules, all while barriers for cooperation decrease. EOSC is a good model for fostering Open Science. As such, it needs services to promote and enable Open Science as well as it needs services to lower the effort required to open access to and re-use of data (in

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	terms of money and time). Against this background, open data repositories might be of use here. Additionally, top-level researchers who open their research data can act as role models to foster Open Science further.
6.7 Reward and evaluation services	Initiatives to establish reward mechanisms as incentives for researchers to provide access to their data, code and other research outputs, as well as services to support their evaluation.
6.8 Services need to conform to RoP that are transparent	Rules of Participation need to be clear on how to get access in terms of money and give a definition on who is actually allowed to use specific datasets.

7 Support Services

Initiatives and Services	**Description**
7.1 Micro services that support researcher's day-to-day routine	Such micro services include digital services related to public archiving, standardized lab record keeping, domain-specific search engines, and the integration of multiple existing platforms.
7.2 Services for checking the forms and formal criteria 7.3 Services to observe ethical guidelines 7.4 Services to support human resource management	All of these tasks are time-consuming. Thus, providing (automated support for) such services saves time for actual research.
7.5 Services to support human peer review processes	AI approaches have value in supplementing and reinforcing human peer review in terms of e.g. running data / software checks, checking biases / reporting standards and potentially some elements of reproducibility. Thus, they could assist in quality control, give access to primary data and support trust in the conclusions derived. Eventually, it is crucial to ask if machines could help to overcome human biases and thus would be better at peer reviewing as algorithms can be inspected and evaluated, offering – in principle – higher transparency than human decision making processes.
7.6 Services for automated deletion processes	As it is impossible to store all data, (automated) re-appraisal and automated deletion processes need to be deviced, considering aspects such as (expected) value of data, feasibility of re-creation and abstraction.
7.7 "Human expert infrastructure" services	Scientific expert programs to support researchers in tasks outside their own core area of expertise, e.g. by providing expert teams in e.g. statistics, programming, data stewardship, and many more. Thus, questions and requirements outside their core domain expertise can be dealt with professionally, increasing the quality and efficiency of research.
7.8 Knowledge Management Systems	Knowledge Management Systems have to be established in order to make better use of what is there already as well as in order to avoid redundancies. Knowledge Management Systems may include services such as search catalogues for experts, ongoing research projects, nano-publication facts and device inventories.
7.9 Machine-actionability	All services should be specifically developed with a focus on being used by and serving machines, specifically access for and by machines, not just humans.

8 Trust Issues in Research Systems

Initiatives and Services	**Description**

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8.1 Initiatives to deal with structural problems such as the non-publication of research results, statistical malpractice and hardly reproducible research	This point of discussion refers to a collapse in society's ability to trust the institutions that adjudicate conflicting research claims, meaning that – irrespective of how good the conclusions of the research community are – the ability to act on them will be severely hampered by the lack of consensus about whether they are trustworthy. Counteracting strategies include the establishment of legible processes to publicly display research processes that result in conflicting research claims, evaluate them and come to conclusions about research results, all while allowing for a failure mode and a mechanism to revisit conclusions and machine learning. Machine learning can help to spot massaged statistics, but needs to be supplemented by some formal set of criteria to be used to (re-)evaluate statistics because it can also be used to massage statistics in ways that are hard for humans to catch.
8.2 Initiatives to (re-)establish trust in (information) technologies	With the development of (information) technologies, AI reasoning and computational processes became so complex that some are not fully understood. That, in turn, poses fundamental obstacles towards trusting (new) technologies and their outcomes, with low acceptance levels when provided by incomprehensible AI algorithms. Ways of (re-)establishing trust include the establishment of regulations to control the development of technologies to some extent, the accompaniment of impact assessment, debates and analyses on possible (side) effects at micro and macro level as well as science communication in order to convey the relevance of science, research and technology to the general public.
8.3 Services for personal data control	Services that enable citizens to get a look at every data that anybody has about them anywhere and for which purpose will make it easier for citizens to entrust research organizations with their data, benefiting research and society.

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