



THE DLIS 2022

Information and Knowledge Management in the 4th Industrial Revolution and COVID-19 Era

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**Hosted by Department of Library and Information Studies
(DLIS)**

25 - 27 April, 2022

VIRTUAL CONFERENCE

**Editor: Prof. P. Jain, Prof. N. M. Mnjama, Prof. B.N. Jorosi & Prof.
O. Oladokun**



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INFORMATION AND KNOWLEDGE MANAGEMENT IN THE 4TH INDUSTRIAL
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EMBEDDED OPEN SCIENCE AS ROADMAP FOR SCIENCE, TECHNOLOGY, AND INNOVATION IN KNOWLEDGE-DRIVEN SOCIETY IN THE 4TH IR

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Abstract

Open Science (OS) is a movement that opens up new ways to make scientific research, data, and dissemination accessible to all levels of an inquisitive society across the globe. OS is a major step towards greater and better public use of information that research generates for knowledge building. The study is exploratory in nature as the study critically reviewed extant literature surrounding Open Science with a focus on science, technology, and innovation in 4IR, especially in the COVID-19 era. This study covered the OS concept and its emergence. Data sharing concepts were reviewed. Different open science schools of thought were explained. Moreover, the principles of OS towards research data sharing were highlighted. The study explored the objectives and characteristics of OS. The benefits of OS to knowledge management towards science, technology, and innovation were discussed. In addition, the paper established the relationship between Open Science and other concepts with the word openness. In addition, the key actors of OS were identified. Furthermore, the challenges of OS were underscored by knowledge management. It was concluded that OS as an umbrella term that encompasses norms of knowledge management with a great potential to flourish in a knowledge-driven society, especially in the COVID 19 era. Among the recommendations is the need for policy development and strategic planning within research institutions themselves to promote openness as a result of the adoption of OS. Also, the needs to develop an Open Science Framework (OSF) for managing the scientific workflow across the entirety of the scientific process.

Keywords: Innovation, Knowledge Management, Open Science, Science, Technology, 4IR, COVID

INTRODUCTION

With the advance of technology and the evolution of the Internet, the activities in research have witnessed transformations in the various facets of research. These have brought various initiatives that promote digitization of information resources, collaboration, and sharing of research output and data. Among the initiatives are open science and open access. Open Science (OS) is the movement to make scientific research (including data, publications, physical samples, and software) and its dissemination accessible to all stakeholders in society at different levels, either unskillful or professional. Foster (2022), defined OS as the practice of science in such a way that others can collaborate and contribute, where research data, lab notes, and other research processes are freely available, under terms that enable reuse, redistribution, reproduction of the

research, and its underlying data and methods. OS could be defined as transparent and accessible knowledge shared and developed through collaborative networks. The Internet serves as a platform for OS likewise open access. With the immense role of the Internet in the achievement of OS initiatives, the supply of available data to researchers has continued to grow. According to McKiernan (2017), OS is called Open Scholarship in English, which represents a culture change in the way stakeholders in the research, education, and knowledge exchange communities create, store, share and deliver the outputs of their activities. Open science refers to all scientific culture that is described by its openness. It may often include features of open access, open data, and open source. According to García et al. (2010), open software owes its deepest roots to Open Access; Open Content are related to open access to the educative, cultural, or divulgated contents that are published under a non-restrictive license that allows copy and distribution, but also the right to modify works. This assertion established that OS has a strong relationship with other initiatives that promote openness. As supported by Mirowski (2018) that OS is passionate to Open Access to scientific content, while Open Innovation transfers the open access principles to creativity in production worldwide. The recent developments have shown a number of multi-stakeholder initiatives, which were funded to develop data-driven research platforms to enhance free access to research outputs and reduce the gap among researchers in their research findings. This creativity has led to data sharing, open access, and open science initiatives. One of the most significant and efficient ways for knowledge sharing is open science because knowledge is absolutely crucial for social evolution in a globalised world. Following United Nations Educational, Scientific and Cultural Organisation- UNESCO's principles, one of today's main goals is to build modern knowledge societies in which all stakeholders must be able to participate in information and knowledge sharing (Gracia & de Figuerola Jose, 2010). For universities and other stakeholders to embrace OS principles, policies, and practices, there is a need for cultural change in organisation, if this transition is to be successfully negotiated. This means a great opportunity for the scientific development and improvement of research outputs in all countries to enhance wide access and improve visibility of research findings using the Internet as a platform.

The Internet plays a clear and important role because it has fundamentally changed the practical and economic realities of distributing scientific knowledge. In modern scientific tradition, collaboration among scientists and the production of scientific public goods have been the engine for scientific production and the justification for public investment in science (David, 2009). Scientists have been expected to collaborate across disciplines and over generations so as to contribute to a stock of interconnected knowledge needed for scientific advance and for a knowledge-driven society. This interconnected knowledge must be managed with the word openness as the watchword.

The point of departure between Open Science (OS) and Knowledge Management (KM) is that OS is more universal and expansive while KM is organization-based and narrowed. It is established that OS provides opportunities for KM to break free of its cocoon status. The strides that open access has made, provide opportunities to make a mark in the sand for the collaboration between OS and KM. This 'de-cocooning' of information and knowledge will add significant propulsion to the growth of knowledge societies and equally add impetus to the growth of the global knowledge economy. This is evidenced by Guédon et al. (2019) that open science is a somewhat wider term and is about maximising the dissemination of knowledge and enabling collaboration by professional researchers and the interested public.

The involvement of OS and KM will lead down the road to a knowledge economy and an informed society which in itself leads down the road to the development of science, technology, and innovation. Science is the intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment. Similarly, science could be seen as the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence. The outcome of scientific research is expected to promote technology development by adopting the principle of openness which is the cardinal point of the Open Science Initiative. The technology could be described as the application of scientific knowledge for practical purposes, especially in the industry for machinery and equipment development.

Technology is the sum of many techniques, skills, methods, and processes used in the production of goods or services or in the accomplishment of objectives, such as scientific investigation (Obodo, 2021). The technology must embrace the principle of openness that will aid collaboration and sharing of knowledge among stakeholders for the purpose of innovation. Innovation plays an essential role in the unending success of any organisation. The end result of any innovation is the product or method or new idea that would contribute immensely to knowledge that would be beneficial to society at large. Scientific knowledge plays an essential role in the discovery of the COVID 19 vaccine and the evolution of the 4IR in our society today. The widespread implementation of Open Science principles increases the rigour, reliability, and reproducibility of scientific results (Besançon et al., 2021) could help optimize research efficiency moving forward, and thus improve health outcomes and economic costs related to COVID-19.

Innovation is germane in any knowledge-driven society because, it gives companies an edge in penetrating markets faster and provides a better connection to developing markets, which can lead to bigger opportunities by adopting the Open Science principle. The 4IR represents a new era of innovation in technology. The 4IR is meant to unlock new market opportunities and fuel growth across the globe (Ramakrishna et al., 2020). This can be facilitated by the principle of OS so that knowledge gained could be widely distributed for the drive of knowledge sharing, use and reuse by the generality of the society.

The 4IR is a term coined by Klaus Schwab in 2016. The 4IR is largely driven by four specific technological developments: high-speed mobile Internet, Artificial Intelligent (AI), automation, the use of big data analytics, and cloud technology (Ndung'u, & Signé, 2020). The impact of 4IR cut across all sectors to increase human productivity, especially in a knowledge-driven society that adopted the OS initiative which serves as a roadmap that connects science, technology, and innovation especially in the Coronavirus era tagged COVID -19.

Coronavirus Disease (COVID-19) is a pandemic disease that emerged and it was caused by the transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). COVID was first identified in December 2019 in Wuhan, China. The name was chosen to avoid stigmatizing the virus's origins in terms of populations, geography, or animal associations (WHO, 2020; The New York Times, 2020). The entire world must continue to embrace the Open Science initiative in their struggle to proffer solutions to the pandemic diseases by sharing information and encouraging collaborations among the stakeholders. Irrespective of the philosophical underpinnings of Open Science, the ultimate goal is to share information, data, and knowledge for a better society. Therefore, the study examined Open Science as a roadmap for science, technology, and innovation in a knowledge-driven society in the 4th IR.

Data Sharing

All over the world, there are demands for data sharing for the benefit of all stakeholders. The emergence of wide distributed networks, cross-platform interoperability, intranets, E-Government online services, and standardization of IP protocols has all enhanced data and information sharing (Yego, 2014). Information could be described as sharable things which can be exchanged, even after you give it away or sell it, you still possess it. The combination of the two terms “data and sharing” needs to be understood before any further discussion. Data is an umbrella term that covers a wide range of meanings and is thus difficult to define (Borgman, 2015). Several studies have failed to provide any widely accepted definition of data or data sharing but provided a definition based on researchers’ perspectives. Many studies (Enke et al., 2012; Pepe, Goodman, Muench, Crosas, & Erdmann, 2014) defined data sharing as a means of making data available to others. This definition is just a paraphrase and is not adequately detailed to cover the multiplicity of data and data-sharing practices. From the perspective of the researcher in the present study, data could be defined as actual records such as textual records, numerical scores, sounds, and images. This suggests that data could be facts, information used to calculate, analyse, or plan something. Researchers agreed that a universal definition of data is a difficult craft. According to Elsevier (2018) what is meant by data and the level of importance assigned to such data differs in various contexts and disciplines. Borgman (2015: 29) defined “data as entities used as evidence of phenomena for the purposes of research or scholarship”. Also, Martone et al. (2018)

defined data as the measurements, observations or facts taken or assembled for analysis as part of a study and upon which the results and conclusions of the study are based. The usefulness of data hinges on the dissemination of data to the users by embracing the Open Science principle of openness. For the sharing concept, it is the act of distribution thus, sharing of data is the allotment of data between or among people of like minds for the purpose of effective utilisation. Furthermore, Martone et al. (2018) opined that data sharing is the publication of primary data and any supporting materials required to interpret the data acquired as part of a research study. Thus, data sharing could be described as a means by which a researcher consents one or more other individuals to use data, with mutual understanding, if not explicit assumption that it is on a reciprocal basis. Borghi and Van Gulick (2018) defined sharing to include "activities involving the dissemination of conclusions drawn from neuroimaging data as well as the sharing of the underlying data itself through a general or discipline-specific repository" (p. 10). There are many types of data sharing: Data shared by individuals, data shared by institutions, information shared between firmware/software (Such as the Internet Protocol (IP) addresses of available network nodes or the availability of disk space for modern technologies such as cloud computing) but all embraced the word "openness" as a cardinal point of Open Science schools of thought.

The Schools of Thought for Open Science

Open Science is an umbrella term that encompasses a multitude of assumptions about the future of knowledge creation and dissemination. Fecher and Friesike (2014) identified five (5) Open Science schools of thought:

1. The infrastructure school: This is concerned with the technological architecture;
2. The public school: This is concerned with the accessibility of knowledge creation;
3. The measurement school: This is concerned with alternative impact measurement;
4. The democratic school: This has to do with the promotion of equal access to knowledge either created or shared knowledge. Thus, access to knowledge is germane.
5. The pragmatic school: The pragmatic belief that knowledge created through joint efforts or a collaboration approach must be shared among peers. Hence, it is concerned with the promotion of collaborative research.

The advocates of pragmatic schools regard Open Science as a method to make research and knowledge dissemination more efficient (Fecher & Friesike, 2014). As alluded by Van der Zee and Reich (2018) Open Science makes research outputs accessible without financial, legal, and technical barriers. Open Science promotes the rights of all people because scientific results have "a powerful effect on people's capacity to speak up as active citizens on matters that are shaping their city and their world" (Suppli et al., 2013: 281). There is a need to trace the development of Open Science for a better understanding of the principle behind Open Science.

The Emergence of Open Science

Economists consider scientific knowledge generated by public research as a public good, which means that everyone can make use of that knowledge at no additional cost once it is made public, generating higher social returns. This thinking is not altogether new. As far back as 1942, Robert King Merton, an American sociologist of science, described a set of ideas that characterised modern science and to which scientists are bound. First and foremost is the notion of common ownership of scientific discoveries, according to which the substantive findings of science are seen as a product of social collaboration and are assigned to the community. Scientists' claims to intellectual property are limited to recognition and esteem. The race to be the first to claim recognition – the so-called priority rule – in science has traditionally been a strong incentive for scientists to make their knowledge public. The term "open science" was coined by economist Paul David (2003) in an attempt to describe the properties of scientific goods generated by the public sector and in opposition to the perceived extension of intellectual property rights into the area of information goods. Open Science is a combination of objective and subjective goals to improve research and science in general.

David underlines that Open Science is "a fragile cultural legacy of Western Europe's history" (David, 2004: 571) when he analyses the history of Open Science back to its appearance during the late sixteenth and early seventeenth centuries and the court patronage system of the late Renaissance Europe (David, 2007). In the 17th Century, the shift toward Open Science was visible in public life and the first science periodicals were published (Willingsky, 2005). The first science association was established and tagged the Royal Society of London for Improving

Natural Knowledge and founded in 1660 with a strong focus on “openness” and including women indicating this shift, too (Willinsky, 2005). The basis for this appearance of Open Science was a change in the opportunities, needs, and demands of western European feudalism and the fragmented and competing noble patrons (Stracke, 2020). In the modern science of the 20th Century, Open Science is closely connected with the emergence of open source and open access according to Willinsky (2005).

Today, open education can be seen as an umbrella concept covering a number of projects revolving around “openness” in the digital world, such as Open Educational Resources, open-source, open access, Open Science, open archiving, and open publishing (Peters, 2008; Peter & Deimann, 2013). Open Science is based on the principles of inclusion, fairness, equity, and sharing, and ultimately seeks to change the way research is done, who is involved, and how it is valued.

The Principles of Open Science

The principles of openness to the whole cycle of scientific research include the following:

1. Quality and integrity: Academic freedom, human rights, and support for high-quality research should be given priority by open science. This can be achieved by bringing together multiple sources of knowledge and making research both methods and outputs widely available for rigorous review and scrutiny, and peer-review with transparent evaluation processes (Gong, 2022).
2. Equity and fairness: Open science is expected to play a key role in ensuring equity among researchers from developed and developing countries (Tennant et al., 2016). Also, it's enabling fair and reciprocal sharing of scientific inputs and outputs. In addition, provision of equal access to scientific knowledge for both producers and consumers of knowledge regardless of geographical location, nationality, age, gender, race, income, socio-economic circumstances, career stage, language, religion, discipline, disability, ethnicity or migratory status, or any other grounds.
3. Collective benefit: Open science promotes openness, thus, belongs to humanity in common and benefits humanity as a whole, especially in global public goods (Cribb &

Sari, 2010). This suggests that scientific knowledge should be openly available and the benefit should be universally shared. The practice of science should be inclusive, sustainable, and equitable, also in opportunities for scientific education and capacity development (UNESCO, 2021)

4. Diversity and inclusiveness: Open science should adopt a diversity of knowledge, practices, workflows, languages, research outputs, and research topics that support the needs of the scientific community and other stakeholders.

In addition to open science core values and principles, there are two broad objectives with many characteristics as enumerated:

The Objectives and Characteristics of Open Science

Open Science (OS) promotes the word “openness. OS is a combination of subjective and objective goals that enhances science in diverse subjects and disciplines as a whole. There are two prime objectives of Open Science as shown in Figure 1, the first objective is the reliability of the research findings while the second objective is trust in scientific research. According to Cook, Lloyd, Mellor, Nosek, and Therrien (2018) and Higgins (2016) both objectives (reliability and trust) have the intention to overcome the fake news from the post-truth age. The two objectives assist each other by complementing and directly interrelated. Furthermore, reliability provides objective credibility as a result of formal correctness and reproducibility. Similarly, trust leads to subjective credibility due to individual confidence building as shown in Figure 1.

The two main objectives open the door to the features of Open Science. Thus the two main characteristics of OS are transparency and openness. For any research to contribute immensely to science, technology, and innovation, the whole research process from the design to the critical review after publication must be transparent and open (Miguel et al., 2014; Banks et al., 2019). Thus the following features explained better the unique characteristic of open science

1. **Transparency:** This is one of the features that promote openness of the Open Science. As reiterated by Cook et al. (2018) that transparency is a core value of science for credibility purposes. Also, it is required to maximize insights, peer evaluation, and evidence.

2. **Openness:** Also, sincerity is germane as a feature of Open Science. This assertion supported Molloy (2011) who opined that openness has become an umbrella word that includes the sharing of research materials and data to promote better understanding, verification, improvement, and re-usage (Miguel et al., 2014)

3. **Reproducibility:** This is another characteristic of Open Science and it is the ability of the research to be reproduced. As established by Nosek and Errington (2017) that reproducibility indicates how robust and repeatable research findings are and it includes the potential replicability (Goodman, Fanelli & Ioannidis, 2016). In addition, reproducibility addresses the influence of decisions during the data analysis (e.g., on outliers and covariates) for consistent findings by different researchers, too (LeBel, McCarthy, Earp, Elson & Vanpaemel, 2018; Spellman, 2017).

4. **Trustworthiness:** It means to which extent research methods and data and the resulting findings can be called reliable and valid representations of reality. This is another feature of OS. There is a core argument in favour of Open Science that enhances the trustworthiness of the research findings. Trustworthiness has a strong relationship with the first objective of Open Science (i.e., higher reliability and validity).

Overall, the research evidence from Open Science is considered more reliable and valid due to its increase in transparency, openness, and reproducibility (Cook et al., 2018; Nosek et al., 2015). Moreover, in the long-term view, trustworthiness should support the second objective of Open Science (i.e., greater trust and confidence in research) by convincing both, the researchers, as well as the citizens and the whole society. From the features of OS, it plays an essential role in overcoming fake news and in building a societal consensus and knowledge community.

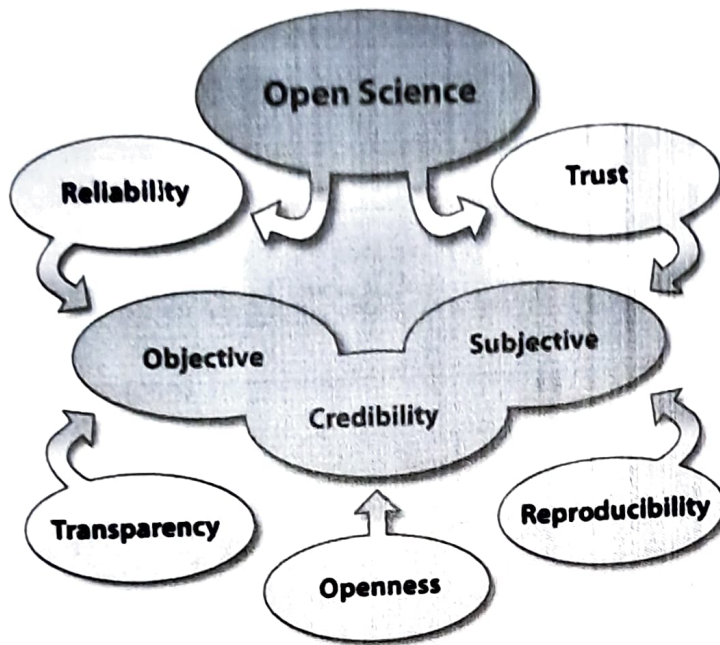


Figure1: The two main objectives- Reliability and Trust of Open Science (Stracke, 2020)

Benefits of Open Science to Science, Technology and Innovation.

The future of Open Science depends on the problems and needs of researchers that can identify and solve the issue. Therefore, the benefits of Open Science focus on its support for the individual researchers and the whole science and technology and community to yield innovation for a knowledge-driven society, especially in COVID -19 era. Open Science has enormous benefits such as:

- 1. Improving scientific efficiency:** OS practice would increase efficiency as evidenced by Zuo et al. (2014). To increase efficiency in scientific production means to be able to achieve more or better scientific outputs (i.e. findings, publications, trained scientists) using the same amount of scientific inputs (i.e. resources). This relates to costs advantages or to learning advantages of openness and collaboration. In turn, we may refer also to dynamic efficiency when there is an increase in the likelihood of improving efficiency in the future given the current state of the art. In turn, collaboration and interaction with the community improve efficiency also by boosting creativity. Open science practices sometimes involve communities participating in analytical or design research stages (not just data collection). In

those cases, non-academic actors or scientists from different disciplines could contribute by sharing knowledge through collaborative efforts that lead to a knowledge-driven society

2. **Transparency and facilitating networking for collaborative efforts.** Open science removes geographical barriers for any potential authors to have adequate access. Also, OS shifts research from the “publish or perish” mantra to a knowledge-sharing ideal because knowledge is freely accessible (Faciolince & Green, 2021).
3. **Improving democratisation of scientific knowledge:** The democratization of scientific knowledge could be achieved through the three complementary mechanisms through which open science practices (Arza & Fressoli, 2017). By improving access to scientific resources; enabling the participation of a wider community in the research process; and making science better understandable for a wider population. Open access increases the pool of information available to anyone in a knowledge-driven society, not just scientists. Nurses, patients, teachers, students may get too interested to learn about the latest
4. **Enhancing research capacity that meets societal needs:** There are three approaches reflected in the literature on how open science practices improve the research capacity to solve societal needs and bring improvement in science, technology, and innovation (Price-Whelan, et al., 2018). The wider access promotes the visibility of the research findings. Secondly, by promoting community actors to participate in the scientific work the research agenda could be better guided towards solving problems affecting that group. When the community is engaged in research people will have the opportunity to grab from their own informed experience and offer inputs for developing solutions that will enhance a knowledge-driven society. Also, the open availability of scientific resources deters private appropriation of such resources. This might lead to finding cheaper solutions to societal problems.
5. **Open Science as an actor for innovation and growth:** It guarantees open access to publicly-funded research outputs and the possibility of the novelty of knowledge sharing by providing infrastructures. OS enhances access to research data and encourages its re-use outside academia. For example, companies particularly small and medium-sized enterprises (SMEs), can access and re-use data, infrastructures, and tools easily and at a reasonable cost,

thus accelerating the implementation of new ideas for innovative products and services (Väänänen, & Peltonen, 2016).

Openness is an essential ingredient in Open Science and other initiatives which are needed in order to capitalize on the results of research and innovation. This shows that there is a strong relationship between Open Science and other initiatives that promote accessibility and visibility of research outputs.

RELATIONSHIP BETWEEN OPEN SCIENCE AND OTHER CONCEPTS WITH THE WORD "OPENNESS"

Open science is the umbrella term for the movement to make scientific research, data, and dissemination accessible to all levels of an inquiring society. Open science encompasses practices such as publishing open research and campaigning for open access, which is generally perceived to make it easier to publish and communicate scientific knowledge. Thus, open science acts as an originator to knowledge management which involves the collection of methods relating to creating, sharing, using, and managing knowledge.

The four (4) core concepts, which are open science, knowledge management, open access, and knowledge economies could be pulled together in identifying the benefits of their collusion for a knowledge-driven society. Open knowledge comprises Open software, Open content, Open Science, and open innovation. Open Science is devoted to the open access to scientific content, while Open Innovation transfers the Open Access principles to the enterprise production world, which is actually vital for the enhancement of organisations. Open Software owes its deepest roots to Open Access; Open Contents are related to open access to the educative, cultural, or divulged contents that are published under a non-restrictive license that allows copy and distribution, also the right to modify works. Open data is the idea that researchers and practitioners such as governments and other institutions embraced. They should not only publish their findings in the form of articles or reports but also share the corresponding raw data sets among the key actors of Open Science.

KEY ACTORS IN OPEN SCIENCE

There are three major actors such as libraries, repositories, and data centres. In addition, other actors in Open Science are researchers, government ministries, funding agencies, universities, and public research institutes. Also, as private non-profit organisations and foundations, private scientific publishers, businesses, and supra-national entities (OECD, 2015). Despite the huge benefits of Open Science that spread across to all stakeholders, however, there are challenges facing OS.

CHALLENGES FACING OPEN SCIENCE INITIATIVE

The challenges facing African countries are enormous such as drought, poverty, and youth unemployment that result from the combination of a population explosion and weak economic growth. It has been argued that the capacity to exploit these opportunities would be greatly enhanced by a strong, multi-state open science system that could drive innovation and development on the continent (Mwelwa et al., 2020). Africa is poorly equipped to benefit from the so-called 4th Industrial Revolution (4th IR) because of generally weak scientific systems that operate in isolation and, with some notable exceptions, fail to create the collaborations that could create economies of scale and generate impact in communities across Africa.

Adoption of the open science movement could be a powerful means of providing evidence-based solutions to put Africa on a path to sustainable development as advocated in the United Nations Sustainable Development Goals and the African Union's Agenda 2063 (Mwelwa, 2020). However, many researchers only support Open Science in theory, and the individual is confronted with various difficulties when putting open science into practice. There are challenges facing Open Science despite its huge benefits. The following are the limitations:

1. **Lack of Political Will:** There is a clear need for political determination to promote Open Science (OS) and integrate it into the government agendas. New policies need to be formulated and developed into clear strategies. Also, the necessary resources need to be allocated in order for these policies to succeed. Hence, there is a need for policy development and strategic planning within research institutions themselves to promote openness as a result of the adoption of OS. In Africa, countries were at various levels of development in OS that are yet to be completed. This might be due to a lack of political commitment in government.

2. **Issue of Trust:** Most researchers and innovators have insufficient trust in the open science approach, particularly with regard to the ownership of results. Also, the intellectual property that might arise from technological developments may discourage the right owner of the knowledge and the importance of publications and prime authorship. In addition, issues that are regarded as important for career progression could not be taken for granted.
3. **Technological:** While there is a tremendous improvement in Information and Communication Technologies (ICTs) and most of the e-infrastructures have grown both in quality and quantity, yet, there is still a wide range of aspects to improve in order to support and ease researchers' workflows to transit to a culture of openness. As reported by Gagliardi, Cox, and Li. (2015) that there is a lack of adequate human and infrastructural capacity in ICT to handle the complexity of open science and the institutionalisation of open science.
4. **Inadequate research databases and journals:** There is no dedicated journal and database for Open Science. This is necessary to motivate researchers to adopt the Open Science initiative.
5. **Financial support:** The main objective of Open Science is to enhance openness which will lead to the higher efficiency of research. Moreover, it will equally yield a better use of resources and foster spillovers in the scientific and innovation systems, significant investments have to be made at the beginning in order to develop the technical, political and, organisational ecosystem of Open Science.
6. **Demand for high impact journals:** The demand by funders, universities, and research institutions for researchers to publish their results in "high impact journals", which are rarely open-access journals, create more problems to open science in Africa, where access to published scientific works, let alone access to the internet, are inhibited by prohibitive costs.
7. **Organisational Readiness:** For research usually takes place within an institutional framework, the organisation itself has to be ready to smooth the transition towards an open research culture, suiting its units, services, and human resources to accommodate an Open Science workflow, thus, developing or acquiring the appropriate skills.

8. **Socio-cultural:** This factor is peculiar to researchers and is related to inadequate awareness of the benefits and importance of opening up their research. Also, the reluctance to change their current workflows and practices regarding the sharing of data along the research process; researchers consider it a time and effort-consuming activity (Palaiologk et al., 2012). Adding to their existing workloads; are the diverse approaches that may have researchers from different disciplines or at different stages in their careers; In addition, lack of clear recognition and a reward system that promotes Open Science practices.

Challenges are meant to be resolved for the benefits derived from open science by the stakeholders. This will facilitate knowledge management towards innovation for the improvement of science and technology.

KNOWLEDGE MANAGEMENT

Knowledge management could be defined as the process of creating, storing, sharing, applying, and re-using organizational knowledge to enable an organization to achieve its goals and objectives. (Tang & Wong, 2015). Knowledge management is an interdisciplinary process of creating, using, sharing, and maintaining an organization's information which requires the adoption of open science for effective management. This will facilitate knowledge sharing that can be manipulated to create an opening for collaboration between open science and knowledge management. Knowledge management is extending the concept of "knowledge" beyond existing concepts like "memory", "storage", and "information". This working definition will be interrogated to identify synergies with open science. The ultimate purpose is to find synergies that will ease the free flow of information for the global growth economy in a knowledge-driven society.

Knowledge management is widely viewed as a range of strategies and practices that are used in an organization to identify, create, preserve and distribute insights and experiences. These insights and experiences are converted into information and knowledge and are very often an important component of an organisation's business strategy. The key principle is sharing of information and knowledge with openness as a watchword.

CONCLUSION

The study used an exploratory approach and reviewed extant literature surrounding Open Science with a focus on science, technology, and innovation in 4IR, especially in the COVID-19 era. Science is the mother of the digital age. The evolution of science into a more open and data-driven enterprise is often referred to as Open Science which crucial for science, technology, and innovation. Open Science as an essential concept has a global capacity to address many of the fundamental issues that human society will continue to face. The World Wide Web software placed in the public domain has created an effective open Internet but science itself has struggled not only to “go digital” but also to “go open”. This is a promise of making Open Science a reality by making the results of publicly funded research, namely scientific publications and research data openly accessible to researchers and innovators in a digital format for a knowledge-driven society, especially in the COVID-19 era. These efforts by researchers, research funding agencies, governments, and the scientific community itself promote an embedded open science as a roadmap for Science, Technology, and Innovation (STI) in a knowledge-driven Society in the 4th IR. These efforts are in the interest of enhancing transparency and collaboration and fostering innovation for a knowledge-driven society, especially in the pandemic period. The Open Science initiative will continue to be the catalyst that liberates the world from COVID-19 and that linger steady growth in facets of science, technology, and innovation for the sake of knowledge sharing in our society with the aid of a supportive model marked 4IR. Thus, the total adoption and use of embedded open science will serve as tools of the digital revolution to enhance the 4IR in areas of collaboration and sharing of research outputs for institutional and national research systems. It can be concluded that the study established the essential role of open science to knowledge-driven toward science, technology and innovation in the Fourth Industrial Revolution.

RECOMMENDATIONS

Based on the available literature to the researcher, the following suggestions were made:

1. Developing Open Science Framework (OSF) is necessary for the effective adoption of Open Science in any research activities. This is an infrastructure for managing the

scientific workflow across the entirety of the scientific process, and it enables openness in an all-inclusive manner. The scientists' workflow is the process by which scientists derive success under any incentive structure while the workflow is the level at which implemented solutions precisely, those that enable openness can be incentivized.

2. There is a need for policy development and strategic planning within research institutions themselves. This will promote openness with the effective adoption of Open Science.
3. Open Science should accommodate indigenous knowledge systems communicated in multilingual formats to expand and guarantee access to millions of researchers who are likely to achieve the potential scientific knowledge for creativity and innovation for development.

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