Current Journal of Library and Information Sciences
Volume. 9, Number 3; July-September, 2024;
ISSN: 2836-9300| Impact Factor: 7.60
https://zapjournals.com/Journals/index.php/cjlis
Published By: Zendo Academic Publishing

OPENING GATES TO OPEN SCIENCE: IMPACT OF DIGITAL TECHNOLOGIES IN FOSTERING OPEN SCIENCE PRINCIPLES IN RESEARCH

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Article Info

Keywords: Open Access, Digital Technologies, Digital Repositories, Artificial Intelligence, Open Access Journals, Pre-print Servers, Open Educational Resources,

DOI
10.5281/zenodo.13757068

Abstract

This comprehensive systematic review investigates the instrumental impact of digital technologies on advancing the foundational principles of Open Science. The primary objective is to conduct a thorough examination of the intricate impacts of technology on enhancing accessibility, transparency, and collaboration within the scientific community. Specifically, it provides a comprehensive overview of the symbiotic relationship between digital technologies and Open Science principles. Drawing upon a diverse array of literature, including studies, articles, and reports from various disciplines, this review explores key themes integral to the paradigm shift toward Open Science. Central to the analysis are the democratization of knowledge facilitated by open access repositories, the transformative capabilities inherent in data-sharing platforms and the collaborative opportunities presented by digital tools in the dissemination of research. This review also explores the challenges and ethical considerations arising from the integration of digital technologies into the scientific process. Through the synthesis of current research, this review aims to provide a comprehensive understanding of how digital technologies have actively contributed to the evolution of Open Science. This elucidates crucial insights for researchers, policymakers, and practitioners eager to harness the complete potential of technology to cultivate a more open and collaborative scientific landscape. By delving into the nuanced interplay between digital tools and Open Science principles, this review offers a valuable resource that not only identifies current trends but also shapes future directions in the dynamic intersection of technology and scientific inquiry. Results suggest that open science practices require interdisciplinary planning and that methodologies, sampling, data collection tools, and online dissemination techniques are suitable for digital platforms.

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Introduction

In the broadest sense, "open science" refers to a paradigm shift in the manner in which scientific methods are conducted (van Dijk, Schatschneider, & Hart, 2021). According to Christensen et al. (2020), an expansive interpretation of Open Science recognizes that the Internet's rapid technological advancements may pave the way for a second scientific revolution that drastically alters scientific standards and research methodologies. The literature review illuminates key dimensions of the evolving relationship between Open Science and digital technologies. Open data, open source software, open journal access, and reproducibility are a few of these principles. Open data, open codes, and transparent methodology, in particular, make it possible to verify the findings of other scientists. However, reproducibility is not the same as that of open science (van Dijk, Schatschneider, & Hart, 2021). Although reputable journals continue to be the main source of peer-reviewed scientific knowledge, these non-journal sources are now a valuable source of information as well. Reports, blogs, articles, and other publications created outside of conventional commercial and academic publication workflows are examples of this "gray literature" (Ramachandran, Bugbee, & Murphy, 2021). The conventional wisdom that scientific findings must be thoroughly validated and verified before publication is being challenged by nontraditional communication channels that enable scientists to share preliminary findings and lessons learned in real time (Gold, 2021).

In the contemporary landscape of scientific inquiry, the transformative influence of digital technologies has become increasingly pronounced, reshaping traditional paradigms and paving the way for a more open and collaborative scientific ecosystem (Vicente-Saez, Gustafsson, & Van den Brande, 2020). It is only natural to carry on this collective development by implementing Open Science practices, which will improve quality, credibility, and rigor of research. Certain Open Science practices, such as data sharing, may cause some scholars to voice concerns, making it one of the most important issues. Sometimes it is problematic or unethical to share materials or data because they may be used for harmful, unethical, or unintentional purposes (Dienlin et al., 2021). As the boundaries of research dissemination, accessibility, and collaboration are evolving, this study seeks to dissect and comprehend the multifaceted impact of technology within the scientific community. The advent of digital technologies has ushered in an era marked by unprecedented opportunities for sharing, transparency, and engagement (Dienlin, et.al, 2021). Open science, a philosophy advocating unrestricted access to research outputs, data and methodologies, finds itself at the forefront of this digital revolution.

The way in which science is shared and conducted collaboratively worldwide has been disrupted by digital technologies, including software, data, and hardware, communication technologies, and the creation of different kinds of digital platforms (Vicente-Saez, Gustafson, & Van den Brande, 2020). These technologies encourage university research teams to adopt new Open Science practices and principles. This opens up new avenues for researchers to collaborate as well as new ways for them to communicate with other universities, research institutes, businesses, governments, individuals, and international organizations.

Social scientists are under pressure to quickly adapt to the ongoing digitization of society and make adjustments in response to the pandemic (Parti & Szigeti, 2021). According to these authors, interdisciplinary planning and preference for methodologies, sampling, data collection tools, and online dissemination techniques appropriate for digital platforms are now more important than ever when it comes to digitizing social sciences. In fact, the spread of Open Science is made easier by the advancement of digital technologies and the rapid expansion of data generated by the scientific community (Tzanova, 2020). Furthermore, researchers have emphasized the significance of information technology advancements in scientific experiments that produce massive amounts of data that can be accessed by researchers via the World Wide Web from any location (Dienlin, et al., 2021). The pursuit of Open Science, as highlighted by Kraker et al. (2011) is characterized by the principles of transparency,

accessibility and collaboration and has witnessed a transformative shift catalyzed by the integration of digital technologies into the scientific landscape. Indeed, these authors point to the democratization of knowledge facilitated by digital technologies as a fundamental aspect of Open Science.

Digital Repositories

Open access repositories, as highlighted by Ali et al. (2018), play a pivotal role in dismantling barriers to information, providing a platform for researchers to share their findings openly. These repositories not only enhance their visibility and accessibility but also contribute to the broad dissemination of scientific knowledge. The transformative potential of data-sharing platforms has emerged as another critical theme in the literature. A recent study by Enema, & kaosisochukwu, (2021) emphasizes how digital technologies enable efficient and secure sharing of research data, fostering a culture of openness. By providing secure and stable environments, these repositories ensure the preservation of diverse scholarly materials, safeguarding them against technological obsolescence and guaranteeing their availability for future generations (Tzanova, 2020). Furthermore, Vicente-Saez, Gustafsson and Van den Brande, (2020) stated that digital repositories promote interoperability by adhering to common standards and metadata schemas, enhancing the discoverability and accessibility of research outputs for both humans and machines, thus fostering a more connected scholarly ecosystem. This shift toward shared data resources not only enhances the reproducibility of studies but also promotes collaborative efforts, echoing the principles of open science, in addition to their role in data sharing and digital repositories contributing to the long-term accessibility of research outputs. Scholars have also explored the Open Archival Information System (OAIS), which provides recommendations on the establishment of archives, the long-term preservation of and access to digital information (Lin, et.al, 2020).

Digital repositories also function as hubs for collaboration, bringing together researchers, institutions, and communities. This centralized space facilitates networking, resource sharing and interdisciplinary collaboration, contributing to a more dynamic and connected research community (Nneka, & Kaosisochukwu, 2021). Compliance with funding and institutional policies is another critical role played by digital repositories, as they assist researchers in adhering to mandates requiring open access to publications and data. Additionally, the integration of digital repositories into researchers' workflows streamlines the adoption of open science principles, making it easier for researchers to deposit and share their outputs without disrupting established practices.

Artificial Intelligence

Artificial Intelligence (AI) streamlines and automates various stages of the research process, from literature review to experimental design and data analysis. By reducing the manual burden on researchers, AI can enable more efficient and reproducible workflows, facilitating the adoption of Open Science principles. Scholars have investigated the role of AI in Open Science and concluded that it raises the stakes of knowledge acquisition and making meaning out of it (Burgelman, et.al, 2019). These authors further claim that AI has already shown potential to accelerate data discovery and data analysis, extract knowledge from research artifacts, and act as a catalyst for further scholarly discussion and change the way research contributions are recognized. AI excels at processing vast amounts of data, enabling sophisticated analysis and pattern recognition. This capability is invaluable for extracting meaningful insights from complex datasets and contributing to the generation of high-quality, reproducible research findings (Uzwyshyn, 2022). The possibilities for AI in Open Science are unlimited, as expounded by Zhang et al. (2023), who posit that AI is an enabler of the most efficient ways of managing workflow to reduce redundancy, thus facilitating transparent access and smart analysis of different resources. AI technologies facilitate the seamless sharing of research data, overcoming the barriers associated with diverse data formats and structures. Through interoperability and standardized approaches, AI promotes collaborative research

efforts, allowing researchers to harness shared datasets to gain a broader and more comprehensive understanding of scientific phenomena (Uzwyshyn, 2022).

AI accelerates the pace of scientific discovery, promotes knowledge synthesis, and supports the open exchange of information within the research community. AI-driven advances contribute to making scientific knowledge more accessible to diverse audiences. Natural language processing (NLP) technologies, for instance, facilitate the creation of user-friendly interfaces that enable non-experts to engage with and comprehend scientific content, thereby promoting inclusivity (Chowdhary, & Chowdhary, 2020). While AI holds immense potential for advancing Open Science, Kang et al. (2020) noted that ethical considerations must be carefully addressed. Issues such as algorithm bias, data privacy, and responsible AI governance require attention to ensure that AI technologies contribute to Open Science in an equitable and responsible manner.

Open Access Journals

Open Access Journals are pivotal to advancing open science by transforming the traditional model of scholarly publishing. These journals facilitate open and free access to research articles, eliminating financial barriers and ensuring that scientific knowledge is accessible to a global audience (Tzanova, 2020). By providing unrestricted online access, Dentin et al. (2021) explained that open access journals promote international collaboration among researchers, accelerating the exchange of ideas and fostering a more interconnected scientific community. According to these authors, open access journals often garner higher visibility and impact because they are freely available, leading to increased citations and sharing of research findings. The rapid dissemination of research through Open Access contributes to the swift progress of science, reducing the time between discovery and application (Morillo, 2020). Furthermore, Demeter, and strati, (2020) highlighted that these journals support public engagement by allowing policymakers, educators, and the general public to stay informed about the latest scientific advancements. Some Open Access Journals also prioritize data accessibility and reproducibility, enhancing research credibility and promoting transparency. According to Singh, and Singh, (2021) stated that commitment to open access journals aligns with the evolving landscape of scholarly communication, experimenting with innovative publishing models like open peer review. Overall, Open Access Journals are instrumental in creating a more inclusive, transparent, and collaborative scientific environment, in line with the principles of Open Science.

The research process is not supported by subscription-based models that journal publishers and their for-profit, marketing-driven dissemination systems promote. The primary financial barrier is that nearly 75% of published scientific articles are behind paywalls, making them inaccessible to anyone outside institutions with the financial means to pay the exorbitant subscription fees (Day, Rennie, Luo, & Tucker, 2020). The potential impact of published research is never fully realized because of financial constraints. Unfortunately, a single person, research institute, or university cannot afford to subscribe to every peer-reviewed journal. Funding agencies in the United States and Europe have implemented regulations requiring data to be easily accessible and publications of all results of publicly funded projects in open access journals (Tzanova, 2020).

Research Networking Platforms

Research Networking Platforms play a crucial role in advancing Open Science by providing a digital space for researchers to collaborate and share their work. These platforms enable the creation of researcher profiles, showcasing expertise, publications, and projects (Verhoef, et.al, 2021). This increased visibility fosters connections and interdisciplinary collaborations, transcending geographical boundaries. Researchers can share various outputs, such as preprints and datasets, thus contributing to open access principles and real-time feedback (Grabher, & van Tuijl, 2020). The platforms also serve as hubs for discussions, forums, and information exchange, promoting transparency and collective problem-solving within the research community. Moreover, these

platforms often integrate with other Open Science initiatives, ensuring seamless sharing of research outputs and aligning with the broader goals of Open Science. By supporting career development, funding exploration and project collaboration, Research Networking Platforms contribute to creating a more connected, transparent and collaborative research ecosystem (Van Dijck, 2020).

Pre-Print Servers

Preprint servers are online resources that facilitate the free distribution of scholarly manuscripts or preprints that have not undergone peer review or have been published in a conventional publishing setting. These tools make it easier to share research quickly, ask for input or collaborate, and rank the importance of discoveries and concepts (Xie, Shen, & Wang, 2021). However, they can also facilitate the dissemination of inaccurate and even fraudulent information and allow the sharing of manuscripts that fall short of the quality standards or methodological information required for research evaluation.

Although scientists understand that pre-print manuscripts should be regarded cautiously, the public or the media might accept them at face value (King, 2020). According to this author, there is a double standard being applied to pre-prints, and there is not a problem with poor information or poorly conducted studies before prints. Furthermore, the expressed concern was that the attention paid to pre-prints would be paid at the expense of actual issues with scientific publishing, and recent commentary warned that crises should not be used as justifications for compromising scientific standards. Preprints are typically received by readers 14 months sooner than their non-preprint counterparts and are linked to five times as many citations (Xie, Shen, & Wang, 2021). These authors discovered that 41% of preprints are ultimately published at peer-reviewed destinations, and the published venues are as influential as papers without preprint versions. Preprint servers play a pivotal role in fostering Open Science by providing platforms for researchers to share their work openly and rapidly with the global scientific community before formal peer review (Hoy, 2020). These platforms, such as arXiv, bioRxiv, and others, allow researchers to disseminate their manuscripts, datasets, and findings promptly, eliminating the lengthy delays associated with traditional publishing processes (Malički, Jerončić, TerRiet, Bouter, Ioannidis, Goodman, & Aalbersberg, 2020). By making research freely accessible to the public, preprint servers contribute to the principles of open access, democratizing scientific knowledge, and removing financial barriers (Massey, Opare, Wallach, Ross, & Krumholz, 2020). Accelerated dissemination encourages collaboration and constructive feedback from the scientific community, fostering a more dynamic and interactive research environment. Preprint servers are particularly valuable for sharing time-sensitive information and contributing to the rapid exchange of ideas and discoveries (Kirkham, et al. 2020). While manuscripts on preprint servers have not undergone formal peer review, their availability allows for early engagement, collaboration, and scrutiny, promoting transparency and openness in scientific discourse (*King, 2020)*. Overall, preprint servers play a crucial role in advancing Open Science by facilitating timely sharing of research outputs and fostering a more inclusive and collaborative scientific landscape.

Semantic Web Technologies

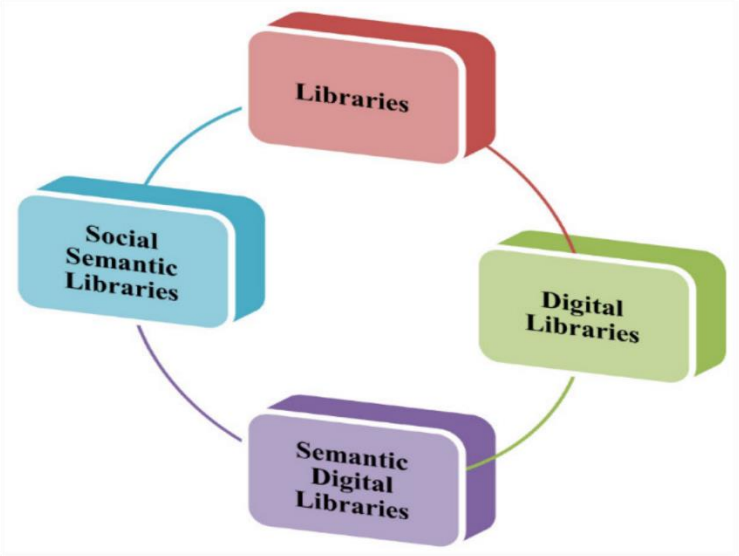
Semantic Web Technologies play a vital role in fostering Open Science within the research domain by enhancing the organization, sharing, and interoperability of scientific data and knowledge. These technologies enable a more intelligent and meaningful representation of data, allowing for better integration and understanding across diverse datasets (Stellato, et.al, 2020). By employing standardized and machine-readable ontologies, Semantic Web Technologies facilitate the creation of linked and interconnected knowledge graphs. This interconnectedness enhances data discoverability (Berners-Lee, Hendler, & Lassila, 2023), making it easier for researchers to find relevant information across various disciplines. Additionally, Semantic Web Technologies contribute to data

interoperability by providing a common framework for describing and linking datasets, thereby enabling seamless integration and information exchange.

Digital libraries are a crucial component of the data foundation that underpins semantic web projects and plays a major role in supporting research and higher education. This was demonstrated by Narayanasamy et al. (2022), who pointed out that the configuration of shared indexes that can be dispersed and widely analyzed is a crucial viewpoint for the digital library (figure 1). For publications to be attributed with subject identifiers, basic metadata must be used to represent the fields in the inventory, and controlled vocabulary must be employed (Stellato et al., 2020). By consolidating the regulated vocabulary in a single location, all clients can then be connected to it via the internet. Library indexes can utilize similar web-available vocabularies to list and increase things with the most applicable terms in the space of concept hierarchy (Martinez-Rodriguez, Hogan, & Lopez-Arevalo, 2020).

Strong fundamentals of the semantic web include linked data, which offer a common framework for data sharing and reuse. This enables computers to comprehend data and information content in addition to reading it (Lampropoulos, Keramopoulos, & Diamantaras, 2020). Through the use of a Resource Description Framework (RDF) and ontologies, researchers can semantically annotate and link their data, leading to a more comprehensive and interconnected research ecosystem (Berners-Lee, Hendler, & Lassila, 2023). The adoption of these technologies supports the principles of Open Science by promoting transparency, collaboration, and accessibility, ultimately fostering a more efficient and interconnected global scientific community.

Figure 1: Application of semantic web technologies in libraries.



Source: *Narayanasamy et al. (2022)*

Open Educational Resources

Open Educational Resources (OER) play a crucial role in advancing Open Science by promoting the free and open sharing of educational materials, fostering accessibility, collaboration, and the democratization of knowledge (Cozart, Horan, & Frome, 2021). OER encompasses a wide range of freely available learning materials, including textbooks, lectures, quizzes, and other educational resources that are openly licensed, allowing users to access, modify, and share them.

The two most important aspects of openness are free internet access and as few restrictions as possible on the use of the resource (Hylén, 2020). This author advocates for an environment in which there are no technical barriers, no price barriers, and as few legal permission barriers as possible for end users. The COVID-19 outbreak had a tremendous effect on education, especially due to financial challenges occasioned by disruptions in activities

(Huang, Tlili, Chang, Zhang, Nascimbeni, & Burgos, 2020). OER removes financial barriers, ensuring that individuals worldwide, regardless of their economic status, can access quality educational materials. In the context of Open Science, OER contributes to the dissemination of scientific knowledge by making educational resources related to research methodologies, scientific principles, and academic tools openly accessible (Otto, Schroeder, Diekmann, & Sander, 2021). This open sharing not only benefits students but also supports researchers in their acquisition of foundational knowledge and skills. Moreover, the collaborative nature of OER encourages educators and researchers to contribute to and improve existing resources, thus fostering a dynamic and inclusive educational environment (McBride, & Abramovich, 2022). Ultimately, the use of open educational resources aligns with the principles of Open Science, promoting an open exchange of knowledge and empowering diverse global audiences to engage in scientific learning and research.

Citizen Science Platforms

Digital citizen science platforms store large amounts of data for many projects and are a place where volunteers can learn how to contribute to projects (Wehn, et.al, 2020). Citizen Science Platforms play a pivotal role in advancing Open Science by engaging the public in scientific research and contributing to the generation of valuable data (Bonney, 2021). These platforms enable individuals, often non-professional scientists or enthusiasts, to actively participate in various research projects, ranging from across all spheres of knowledge (Sánchez-Clavijo, et.al., 2021), providing accessible tools and interfaces. These platforms empower diverse communities to collect and contribute data, fostering a collaborative approach to scientific inquiry. The openness of these initiatives promotes transparency, allowing a broader audience to access and scrutinize the collected data (Schaaf, et al., 2024). Additionally, these authors argued that citizen science platforms enhance public participation in scientific endeavors by bridging the gap between researchers and the community. This involvement not only accelerates data collection on a large scale but also increases public awareness and understanding of scientific processes. The inclusive nature of citizen science platforms aligns with the principles of Open Science (Liu, Dörler, Heigl, & Grossberndt, 2021), emphasizing collaboration, accessibility, and the democratization of scientific knowledge, ultimately contributing to a more robust and participatory scientific ecosystem.

Materials and Methods

This study exclusively employs systematic literature review to investigate the integral role of digital technologies in advancing Open Science principles. To select articles for review, the authors conducted manual searches of the Web of Science and Google Scholar. The authors focused on journal publications published between January 1, 2020 and March 2024 and screened articles based on quality, originality, and clarity. The scope of this review is restricted to the role of digital technologies in fostering open science and specifically reviews literature on the effects of digital repositories, artificial intelligence, open access journals, research networking platforms, pre-print servers, semantic web technologies, open educational resources and citizen science platforms.

The systematic literature review is structured as follows:

1. **Search Strategy:** A systematic and exhaustive search strategy is developed to identify relevant literature. This involves the use of academic databases, scholarly journals, and reputable repositories. Keywords, search terms, and inclusion/exclusion criteria are defined to ensure the retrieval of pertinent studies within the scope of the research question.
2. **Inclusion and Exclusion Criteria:** Clearly defined inclusion and exclusion criteria were applied to filter the literature. Studies included in this review directly address the impact of digital technologies on Open Science principles. Excluded are studies outside the defined scope, those lacking relevance, and those with insufficient methodological rigor.

3. **Data extraction: A structured** data extraction process is implemented to systematically collect relevant information from selected studies. Key data points include authorship, publication year, research design, methodologies employed, and primary findings. This standardized approach enhances the reliability and comparability of the extracted data.
4. **Quality Assessment:** The quality and rigor of each included study were critically assessed to ensure the reliability of the evidence. This involves evaluating the study design, sample size, methodology, and appropriate analytical approaches. Quality assessment is essential for establishing the credibility and validity of the synthesized findings.
5. **Data Synthesis and Analysis:** The extracted data is synthesized using thematic analysis. Themes and patterns related to the impact of digital technologies on Open Science principles are identified and systematically categorized. This process allows for the organization of diverse findings into coherent narratives, contributing to a nuanced and comprehensive overview of the subject.
6. **Limitations and Critical Reflection:** This study acknowledges and addresses the potential limitations inherent in the systematic literature review methodology. Recognizing the bias introduced by the available literature and potential research gaps, this study provides a critical reflection on the scope and generalizability of the findings.

Results

The findings reveal that digital technologies play a crucial role in promoting open access to research outputs and ensuring the preservation of scholarly artifacts. Studies highlight the importance of interoperability, adherence to metadata standards, and long-term sustainability for the effective management of research data, results, and dissemination. Artificial intelligence technologies are increasingly integrated into research processes to enhance the efficiency, accuracy, and reproducibility of data analysis, literature mining, and knowledge discovery. Authors agree that open access journals are instrumental in democratizing access to scientific knowledge by eliminating subscription barriers, with various publishing models contributing to sustainability and inclusivity. Additionally, research networking platforms facilitate collaboration and interdisciplinary networking among scholars, enhancing visibility and connectivity within the scientific community.

Although pre-print servers attracted diverse opinions from the sampled authors, they provide researchers with a swift and transparent channel for disseminating preliminary findings, thus speeding up scientific discourse and discovery. Semantic web technologies enable seamless integration and discovery of heterogeneous scientific data, fostering interdisciplinary collaborations, and Open Educational Resources initiatives promote equitable access to education, supporting lifelong learning endeavors, and democratizing education globally. Lastly, citizen science platforms engage the public in scientific research activities by facilitating large-scale data collection and collaboration, thus contributing to the democratization and advancement of scientific endeavors while enhancing science literacy and community engagement.

One of the most prominent concerns arising from this study however, regards data sharing. Sometimes the sharing of materials or data is problematic or unethical because they could be used for unintended, harmful, or unethical purposes. Scholars believe that regulatory framework reforms should be implemented to streamline data sharing among researchers. There is also a general agreement among scholars that scientists do not use opportunities in the digital world, mainly because of a lack of relevant training and preparedness. It is believed that open science practices require interdisciplinary planning and preference for methodologies, sampling, data collection tools, and online dissemination techniques suitable for digital platforms.

Discussion

To advance open science practices, active participation is essential from both supporting organizations like data programs and journal publishers, as well as individuals within the research community. Individual researchers play a crucial role as advocates for open science by advocating for various best practices. First, they should ensure that their data are accessible in an open repository formatted according to a nonproprietary standard. In addition, they should assign a DOI to their data and provide transparent licensing information and usage constraints. AI systems, methods, and models can serve as efficient knowledge-sharing tools, especially when designed for wide deployment with minimal energy and computing requirements. However, achieving this requires international AI cooperation grounded in multidisciplinary research and Open Science principles to expedite the translation of research into globally applicable solutions that are adaptable to local contexts. The open-access model facilitates free and unrestricted access to scholarly literature, including both peer-reviewed journals and unreviewed preprints. The widespread adoption of technological advancements, alongside investments in relevant technologies and training for research and administrative personnel by academic institutions, publishers, and scholarly repositories will further support the dissemination of knowledge.

Conclusion

This systematic literature review elucidates the pivotal role of digital technologies in fostering Open Science principles, providing a comprehensive overview of their contributions, challenges, and future prospects. By leveraging digital repositories, artificial intelligence, open access journals, research networking platforms, pre-print servers, semantic web technologies, open educational resources and citizen science platforms, researchers can promote openness, collaboration and accessibility in scholarly research, thereby advancing collective knowledge and addressing societal challenges.

Recommendations

The results underscore the transformative impact of digital technologies in advancing Open Science principles across diverse domains. However, challenges such as data privacy, quality control, funding sustainability, and the digital divide persist and require concerted efforts from stakeholders. Future research directions may include exploring emerging technologies, policy frameworks, and community-driven initiatives to further enhance open science practice in the digital age.

Acknowledgment

We extend our appreciation to the authors of the peer-reviewed articles included in this review for their rigorous research and insightful findings. Their dedication to advancing knowledge and promoting openness in scholarly communication were instrumental in informing our analysis. We acknowledge the support and guidance provided by our academic advisors and colleagues throughout the course of this study. Their expertise and feedback have been essential in refining our methodology and interpretation of results. We thank the anonymous reviewers for their patience and time in improving the quality of this article.

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