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Збірник матеріалів конференції вміщує результати наукових досліджень наукових співробітників, викладачів вищих навчальних закладів, докторантів, аспірантів, студентів з актуальних проблем гуманітарних, природничих і технічних наук

Відповідальність за грамотність, автентичність цитат, достовірність фактів і посилань несуть автори публікацій

УДК 004.94

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THE IMPACT OF OPEN SOURCE SOFTWARE ON ACCESSIBILITY IN SCIENTIFIC RESEARCH AND EDUCATION

This article examines how open-source software enhances accessibility in scientific research and education by removing financial barriers and democratizing access to high-quality tools. The research examines the economic benefits, addresses challenges related to the digital divide, and investigates the role of programming languages, such as Python and R, in facilitating scientific collaboration. Special attention is given to the challenges faced by developing countries and the potential of cloud computing solutions.
Keywords: *open source software, scientific research, educational accessibility, digital divide, FAIR principles, reproducibility, collaborative research, cost reduction.*

У статті досліджується, як відкрите програмне забезпечення трансформує доступність наукових досліджень та освіти шляхом усунення фінансових бар'єрів та демократизації доступу до високоякісних інструментів. Дослідження аналізує економічні переваги, розглядає виклики цифрового розриву та вивчає роль мов програмування, таких як Python та R, у сприянні науковій співпраці. Особлива увага приділяється викликам країн, що розвиваються, та потенціалу хмарних обчислювальних рішень.
Ключові слова: *відкрите програмне забезпечення, наукові дослідження, доступність освіти, цифровий розрив, принципи FAIR, відтворюваність, спільні дослідження, зниження витрат.*

In recent decades, scientific research and education have undergone significant changes, mainly due to the widespread adoption of open-source software. Unlike traditional proprietary options, which can be expensive and difficult to access, open-source tools have revolutionized the way researchers, students, and institutions utilize scientific computing and data analysis. Open-source tools have significantly expanded access to advanced scientific resources, with studies indicating that organizations can reduce costs by up to 87% when adopting open-source solutions instead of proprietary alternatives. Studies show that organizations can save up to 87% in costs by choosing open-source scientific tools over proprietary ones. These savings are significant for institutions in developing countries, where limited budgets often restrict access to the latest research tools and technologies. This shift is about more than just saving money. Open-source software embodies transparency, collaboration, and knowledge-sharing values that are central to science. When researchers can examine, modify, and enhance the tools they use, it opens up new opportunities for innovation that closed, proprietary software cannot offer.

As Andreatos (2023) notes in his study of cyber security education, open-source software provides cost-effective solutions that democratize access to advanced technologies, particularly for educational institutions with limited financial resources [1, p. 45]. This perspective is further supported by Barba (2022), who argues that open-source software plays a fundamental role in research reproducibility by promoting transparency and enabling distributed collaboration among researchers worldwide [2, p. 42]. The researcher emphasizes that reproducibility is essentially a trust-building endeavor, and open-source practices help establish this trust through transparent methodologies and accessible tools. One of the most compelling aspects of open-source software lies in its ability to eliminate traditional financial barriers. Having observed numerous educational institutions struggle with software licensing costs, I've seen how these expenses can consume significant portions of already limited budgets. Commercial scientific software packages often cost hundreds to thousands of dollars per user annually, creating substantial barriers for smaller institutions. The economic benefits extend beyond simple cost reduction. When institutions allocate funds previously used for software licenses toward research purposes, the impact is significant. A university that saves $100,000 annually on software can redirect those funds to lab equipment, student scholarships, or new research projects. Secondary schools have reported cost reductions of 24% per computer, which becomes significant when multiplied across entire school districts. These economic benefits are especially strong because they last over time. Unlike proprietary software requiring ongoing license fees, open-source solutions offer steady, predictable costs, helping institutions plan technology budgets without worrying about sudden vendor price increases. The digital divide remains a significant challenge to making science and education accessible worldwide. However, the digital divide poses ongoing challenges, as low internet usage in less developed regions around 36% compared to the global average creates inequities in accessing shared knowledge and tools. This disparity has profound implications for scientific collaboration and knowledge sharing. If researchers in developing countries cannot access the same tools and databases as those in wealthier nations, it creates unfair conditions and slows global progress. Cloud computing offers a way forward by delivering powerful resources online, though it depends on reliable connectivity, which is still lacking in many areas. Institutions have responded creatively, establishing shared computing centers or forming international partnerships to pool resources and expertise. However, this solution requires reliable internet connectivity, which remains problematic in many regions.

Some educational institutions have found innovative ways to address these challenges. Some set up regional computing centers to share costly software and hardware. Others partner with institutions in developed countries, sharing resources and knowledge through joint research programs that benefit all parties involved. Open-source programming languages, such as Python and R, have revolutionized how scientific research is conducted. Having used both older statistical software and these newer tools, I can attest they are much more accessible and useful. This change reflects a move toward more open and reproducible research practices. Python has become especially important in scientific computing. Libraries like NumPy, SciPy, and pandas make it as powerful as, or even better than, costly proprietary software. NumPy is downloaded hundreds of millions of times each month, demonstrating the widespread adoption of these tools. R has significantly changed statistical analysis. Created to make advanced statistics accessible to non-programmers, R now offers more than 15,000 packages on CRAN, providing tools for nearly any statistical method or scientific application. This flexibility lets researchers find or create the exact tools they need. These open-source communities collaborate to continually enhance their tools. When researchers develop new methods or identify problems, they can directly contribute to software improvement. This approach enables scientific software to adapt quickly to researchers' needs, which is more challenging with proprietary alternatives.

Recently, it has become clear that many scientific studies cannot be repeated by other researchers. Open-source software helps by making research tools and methods transparent and verifiable, improving reproducibility. Proprietary software often operates like a "black box" because its inner workings are hidden. This makes it difficult for others to understand or repeat published analyses. Open-source software addresses this by making all code publicly available, allowing researchers to examine and modify how analyses are performed. The FAIR principles (Findable, Accessible, Interoperable, and Reusable) help guide better research data management and sharing. These principles align well with open-source software philosophy, strengthening research overall. When researchers use open-source tools and share their code, others can replicate the work, build upon it, or apply similar methods to new data. Tools like Git and GitHub have transformed how researchers handle and share their code. Jupyter notebooks are especially useful because they combine code, results, and explanations in one place, making it easier to document analytical procedures and enabling others to understand and replicate the work [6].

Despite numerous benefits, significant challenges remain for widespread open-source adoption. Technical issues are often the biggest challenge for many institutions. Open-source software can be powerful, but sometimes requires more technical expertise to set up and maintain than commercial software. Smaller schools or those without strong IT teams may struggle to provide necessary support. Switching from familiar commercial software to open-source alternatives can be challenging. Researchers who have spent years mastering specific tools may be reluctant to invest time learning new systems, especially if benefits aren't immediately apparent. This hesitation is understandable, given the time investment required and productivity pressures researchers face. Organizational inertia presents another significant challenge. Institutions often have existing vendor contracts, established workflows, and staff trained on specific systems. Changing these requires financial investment and careful change management. Risk-averse leaders may view switching to unfamiliar systems as too risky despite potential benefits.

Looking toward the future, several trends could significantly enhance open-source software's impact on scientific research and education accessibility. The integration of artificial intelligence capabilities into open-source scientific tools presents opportunities for enhancing research capabilities while maintaining accessibility. Cloud computing can help address ongoing issues with open-source adoption. When complex tools are available through web browsers rather than requiring local installation, it significantly reduces technical barriers many institutions face [5, p. 2]. This approach also enables resource sharing among organizations. Educational integration represents another critical area. Rather than treating open-source software as separate from standard curricula, schools should incorporate these tools as normal components of science education. This ensures students develop competency with open-source tools as part of their academic development. Policy interventions could play important roles in accelerating adoption. Government funding agencies could require publicly funded research to use open-source tools when feasible, or provide dedicated funding for open-source software development and maintenance.

In conclusion, open-source software stands as a powerful force for democratizing science and education, delivering substantial cost savings and promoting core values of transparency and collaboration. By overcoming infrastructure challenges and the digital divide through innovative solutions and international efforts, it enables equitable participation worldwide.

However, the benefits extend far beyond economics. Open-source software embodies principles of transparency, collaboration, and shared knowledge that align perfectly with scientific ideals. When researchers can examine, modify, and improve their tools, it creates innovation opportunities impossible in proprietary environments. The global implications are particularly significant. While challenges persist in addressing infrastructure limitations and digital divides, open-source software provides a foundation for more equitable participation in scientific research worldwide [4, p. 62]. When talented researchers in developing countries can access the same sophisticated tools as colleagues in wealthy institutions, it benefits the entire global scientific enterprise. The emergence of programming languages like Python and R demonstrates how open-source solutions can not only match but exceed the capabilities of expensive proprietary alternatives. Looking forward, continued success will depend on addressing persistent challenges around technical support, training, and institutional adoption through strategic investments in infrastructure, supportive policy changes, and international collaboration frameworks. As we move forward, the choice between proprietary and open-source solutions is shifting from technical capabilities to values and vision for science's future. The evidence strongly suggests open-source approaches offer superior solutions for building inclusive, innovative, and sustainable scientific research and educational systems for the 21st century.

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MODERN ARCHITECTURES FOR INFORMATION RETRIEVAL AND RECOMMENDER SYSTEMS

This paper explains, in simple words, how modern search and recommendation systems work. We start from keyword matching (BM25) and then describe vector-based methods (dual-encoders), token-level matching (ColBERT) and re-ranking. We also show why fast vector indexes like FAISS and HNSW are needed to search large collections. For recommendations, we outline the two-stage design (candidate generation → ranking) and neural models such as Neural Collaborative Filtering. We finish with evaluation notes and practical trade-offs.

Keywords: *information retrieval; recommender systems; BM25; dense retrieval; vector indexes; two-stage ranking; evaluation.*

У цій статті простими словами пояснюється, як працюють сучасні системи пошуку та рекомендацій. Ми починаємо з пошуку за ключовими словами (BM25), а потім описуємо векторні методи (подвійні кодери), пошук на рівні токенів (ColBERT) та переранжування. Ми також показуємо, чому для пошуку у великих колекціях потрібні швидкі векторні індекси, такі як FAISS та HNSW. Щодо рекомендацій, ми описуємо двоступеневий дизайн (генерування кандидатів → ранжування) та нейронні моделі, такі як Neural Collaborative Filtering. На завершення ми наводимо примітки щодо оцінки та практичні компроміси.

Ключові слова: *пошук інформації; системи рекомендацій; BM25; щільний пошук; векторні індекси; двоступеневе ранжування; оцінка*

Search (IR) and recommendation (RS) solve very similar problems. In search, the user enters a query and expects to receive high-quality documents. In recommendations, the system suggests items that may be of interest to the user. In both cases, the collection is huge, and the response must be provided quickly. Therefore, many real-world systems use a simple idea: a fast first pass to collect candidates and a slower second pass to rank them carefully [1, pp. 191–193]. This division makes it easier to scale and debug the entire pipeline. The document and query can be represented as lists of words with weights. BM25 is a practical formula that increases the weight of important words but normalises the length of the document. It works okay without any training data and remains a strong choice for the first pass in real-world systems [6, pp. 333–340; 5, pp. 1–4].