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INTEGRATION OF PHYSICS PRACTICUM RESULTS INTO INTERNATIONAL OPEN DATA PLATFORMS: OPPORTUNITIES FOR ENHANCING PROFESSIONAL COMPETENCE

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Abstract. *The integration of physics practicum results into international open data platforms represents a novel approach to enhancing students' scientific and professional competencies. Traditional laboratory practices often remain limited to local institutional archives, restricting opportunities for collaboration, comparative analysis, and contribution to the global scientific community. This study proposes a methodology for aligning laboratory outcomes with open science principles by uploading and systematizing students' experimental results in platforms such as Zenodo, Figshare, and the Open Science Framework. The research highlights how this integration fosters data literacy, critical thinking, and research-oriented skills, while simultaneously improving transparency and reproducibility in physics education. The findings suggest that open data integration can transform the physics practicum into a more dynamic, collaborative, and competence-based learning environment.*

Key words: *physics practicum; open data; cloud integration; professional competence; open science; laboratory education.*

Annotatsiya. *Fizika praktikum natijalarini xalqaro ochiq ma'lumotlar platformalariga integratsiya qilish talabalarning ilmiy va kasbiy kompetensiyalarini oshirishga qaratilgan yangi yondashuvni ifodalaydi. An'anaviy laboratoriya mashg'ulotlari ko'pincha mahalliy ta'lim muassasalari arxivlari bilan chegaralanib qoladi, bu esa hamkorlik, taqqosiy tahlil va jahon ilmiy hamjamiyatiga hissa qo'shish imkoniyatlarini cheklaydi. Ushbu tadqiqot talabalarning eksperimental natijalarini Zenodo, Figshare va Open Science Framework kabi platformalarga joylashtirish hamda tizimlashtirish orqali laboratoriya natijalarini ochiq fan tamoyillari bilan uyg'unlashtirish metodologiyasini taklif etadi. Tadqiqot shuni ko'rsatadiki, bunday integratsiya ma'lumotlar savodxonligini, tanqidiy fikrlashni va tadqiqotga yo'naltirilgan ko'nikmalarni shakllantirish bilan birga, fizika ta'limida shaffoflik va qayta tekshirish imkoniyatlarini ham kuchaytiradi. Natijalar shuni anglatadiki, ochiq ma'lumotlarni integratsiya qilish fizika praktikumini yanada dinamik, hamkorlikka asoslangan va kompetensiyaga yo'naltirilgan o'quv jarayoniga aylantirishi mumkin..*

Kalit so'zlar: *fizika praktikumi; ochiq ma'lumotlar; bulutli integratsiya; kasbiy kompetensiya; ochiq fan; laboratoriya ta'limi.*

Аннотация. *Интеграция результатов физического практикума в международные платформы открытых данных представляет собой новый подход к повышению научных и профессиональных компетенций студентов. Традиционные лабораторные практики зачастую ограничиваются локальными архивами учебных заведений, что сужает возможности для сотрудничества, сравнительного анализа и вклада в мировое научное сообщество. В данном исследовании предлагается методология согласования лабораторных результатов с принципами открытой науки посредством загрузки и систематизации экспериментальных данных студентов на такие платформы, как Zenodo, Figshare и Open Science Framework. В работе подчеркивается, что подобная интеграция способствует развитию data-грамотности, критического мышления и исследовательских навыков, одновременно повышая прозрачность и воспроизводимость в физическом образовании. Полученные результаты показывают, что внедрение открытых данных способно преобразовать физический практикум в более динамичную, коллаборативную и компетентностно-ориентированную образовательную среду.*

Ключевые слова: *физический практикум; открытые данные; облачная интеграция; профессиональная компетентность; открытая наука; лабораторное образование.*

Introduction. Physics education has long been regarded as a central component in shaping scientific literacy, analytical reasoning, and professional competence. In higher education, physics does not merely provide theoretical knowledge; it also cultivates the ability to conduct experiments, analyze empirical data, and interpret results within real-world contexts. One of the most effective mechanisms to achieve these educational outcomes is the *physics practicum*, which allows students to bridge the gap between abstract theory and experimental verification.[1] Through laboratory work, learners engage with scientific instruments, measure physical quantities, and observe fundamental principles of nature in practice. This process significantly contributes to the formation of critical thinking, problem-solving abilities, and research-oriented skills. Despite its recognized importance, traditional approaches to laboratory education are increasingly seen as limited in scope. In many institutions, students’ laboratory results are recorded in written reports or local archives that remain inaccessible to external audiences. These outcomes, while valuable for immediate educational purposes, rarely contribute to broader scientific discussions or comparative studies across institutions and countries. As a result, valuable experimental data often remain underutilized, and opportunities for collaboration, reproducibility, and international engagement are constrained.[2]

In contrast, the last decade has witnessed a rapid expansion of the *open science* movement, which promotes transparency, accessibility, and collaboration in the generation and dissemination of scientific knowledge. A central element of this movement is *open data*, defined as research data that are made freely available to the public for use, re-use, and redistribution. International platforms such as **Zenodo**, **Figshare**, and the **Open Science Framework (OSF)** have emerged as leading repositories for storing, systematizing, and sharing research data in standardized and globally accessible formats. These platforms not only provide secure long-term

storage but also facilitate citation, version control, and metadata integration, thereby enabling reproducibility and collaborative innovation.

While the integration of open data practices has been widely explored in professional research contexts, their implementation in undergraduate and graduate education—particularly in physics practicums—remains underdeveloped. Recent studies in science education emphasize the need to equip students with *twenty-first century competencies*, including digital literacy, data management, and collaborative research skills. Embedding open data principles into physics laboratories has the potential to directly address this need. By requiring students to upload and curate their experimental results on open platforms, educators can simultaneously enhance transparency and reproducibility while also preparing students for participation in global scientific networks.

Moreover, adopting open data strategies in laboratory education aligns with broader trends in digital transformation and internationalization in higher education. Universities worldwide are increasingly encouraged to foster student participation in global research initiatives, cross-institutional projects, and collaborative learning environments. Physics practicums, when integrated with open data platforms, can become hubs for such activities, offering students the opportunity not only to learn scientific methods but also to contribute meaningfully to international knowledge exchange.

Despite these opportunities, the practical integration of open data into laboratory education is not without challenges. Issues such as data standardization, ethical considerations, intellectual property rights, and students’ digital preparedness must be addressed. Furthermore, successful implementation requires the development of clear pedagogical models that balance the educational objectives of the physics practicum with the technical and ethical requirements of open science practices. Against this backdrop, the present study aims to explore and propose a framework for incorporating international open data platforms into the physics practicum. The central hypothesis is that this integration will not only improve the scientific quality and transparency of laboratory work but also significantly enhance students’ professional competence by fostering data literacy, digital skills, and collaborative problem-solving abilities.[3] Specifically, the study seeks to answer the following research questions:

1. How can students’ physics practicum results be systematically prepared and integrated into international open data repositories?
2. What competencies are developed in students through the process of contributing laboratory results to global open science platforms?
3. What pedagogical and technical challenges arise in the implementation of this approach, and how can they be effectively addressed?

By addressing these questions, the study aims to demonstrate that physics practicums—traditionally viewed as local and institution-bound educational activities—can be transformed into globally connected, competence-based learning environments. The findings are expected to provide both theoretical insights and practical guidelines for integrating open science principles into physics education, thereby contributing to the modernization of laboratory teaching and the professional development of students.

Methods

This study employed a mixed-method design combining pedagogical experimentation with qualitative and quantitative analysis of student performance. The central focus was the integration of international open data platforms into physics practicum courses in higher

education. The research was conducted during the 2024–2025 academic year at two universities, involving undergraduate students majoring in physics and engineering education. A total of 68 students participated in the experimental group, while 64 students formed the control group.[4]
The intervention was based on a step-by-step framework for uploading and systematizing laboratory results on open data repositories:

1. **Preparation of experimental data**: Students were instructed to record measurements, uncertainties, and error analyses in a standardized digital format (Excel).
2. **Metadata generation**: Each dataset included metadata fields such as experiment title, date, instruments used, student contributors, and keywords.
3. **Platform selection**: Internationally recognized repositories (Zenodo, Figshare and the Open Science Framework) were selected based on accessibility, licensing policies, and data storage capabilities.
4. **Uploading process**: Students uploaded their datasets under Creative Commons licenses, ensuring openness while maintaining academic integrity.
5. **Validation and feedback**: Supervisors verified uploaded results for accuracy and completeness, followed by peer-review style feedback sessions.

Pedagogical Framework[5]

The educational model was designed according to *competence-based learning principles*. The experimental group was guided through activities that emphasized:

- **Data literacy**: Understanding the structure, management, and sharing of scientific data.
- **Digital competence**: Mastering open data tools and repository platforms.
- **Collaborative research skills**: Engaging in peer discussions and cross-group validation of datasets.

Data Collection and Analysis

Three instruments were used for evaluating the impact of the intervention:

1. **Pre- and post-tests**: Designed to measure students’ understanding of data management, reproducibility, and open science concepts.
2. **Observation protocols**: Classroom and laboratory observations were conducted to assess students’ engagement and collaboration.
3. **Survey questionnaires and interviews**: Gathered students’ perceptions of open data integration, challenges encountered, and self-reported competence development.

Quantitative data were analyzed using statistical software , focusing on comparative performance between the control and experimental groups. Qualitative data from interviews and open-ended survey responses were coded thematically to capture patterns in students’ experiences.[6]

Results

The implementation of open data integration into the physics practicum demonstrated significant improvements in both students’ academic performance and their professional competencies. Results are presented in three subsections: quantitative outcomes, qualitative findings, and comparative analysis between the experimental and control groups.[7]

Quantitative Outcomes

Pre- and post-test scores indicated measurable progress in students’ understanding of open science and data management principles. The experimental group (n = 68), which actively engaged in uploading and curating datasets, showed an average improvement of **31%** in post-test results compared to a **12%** increase in the control group (n = 64).

Competency Area	Control Group (Gain %)	Experimental Group (Gain %)
Data Literacy	+10%	+34%
Digital Competence	+14%	+39%
Collaborative Research Skills	+11%	+28%
Ethical and Open Science Awareness	+13%	+31%

These findings confirm that systematic engagement with open data repositories enhances students’ mastery of digital tools, improves their awareness of reproducibility standards, and strengthens their collaborative learning abilities.[8]

Qualitative Findings

Survey questionnaires and interviews provided further evidence of students’ positive perceptions:

- **85%** of participants in the experimental group reported that publishing their laboratory data on international platforms motivated them to conduct experiments more carefully and responsibly.
- **79%** highlighted an increase in confidence when handling scientific data, noting that their contributions could be accessed by a global audience.
- **72%** expressed that collaborative discussions during the validation process improved their ability to critically evaluate not only their own data but also the work of their peers.

Comparative Analysis

When comparing both groups, the experimental cohort consistently outperformed the control group across all measured competencies.[9] Notably, data literacy and digital competence showed the largest gains, reflecting the direct impact of working with open repositories. Furthermore, observational records indicated that students in the experimental group were more engaged during laboratory sessions, frequently discussing data validation and reproducibility.

These results suggest that integrating open data platforms into the physics practicum is not only feasible but also transformative for student learning. The outcomes highlight the potential of open science practices to enhance educational quality, foster global collaboration, and develop key competencies necessary for future scientific careers.[10]

Discussion

The results of this study demonstrate that integrating open data platforms into physics practicums can significantly enhance students’ scientific competencies, particularly in the domains of data literacy, digital competence, and collaborative research.[11] These findings are consistent with international research highlighting the growing importance of open science practices in higher education. However, the present study extends these insights into the realm of undergraduate and graduate physics education, offering evidence that students can also benefit from early exposure to open science practices. One of the most notable outcomes of the intervention was the improvement in students’ data literacy. [12]This competency has been recognized as essential in the digital era, where researchers must be able to organize, analyze, and share scientific information effectively. By engaging with repositories such as Zenodo and Figshare, students not only learned to manage datasets but also gained a deeper appreciation for the ethical and professional responsibilities associated with data sharing. Another significant

finding was the enhancement of collaborative research skills. The peer-review style validation and group discussions required for uploading data to open platforms fostered a culture of critical inquiry and collective problem-solving. Despite these promising outcomes, several challenges must be acknowledged. First, the process of standardizing laboratory data proved to be time-consuming and required additional instructor guidance.[13] This suggests that faculty development and clear pedagogical models are critical for successful implementation. Second, digital infrastructure and language barriers may limit the accessibility of international repositories for some students, particularly in institutions with limited resources. Third, ethical considerations, including data privacy and intellectual property rights, remain areas requiring careful attention in educational settings.

Nevertheless, the overall evidence suggests that the benefits of integrating open data platforms into physics practicums outweigh the challenges.[14] By preparing students for participation in open science initiatives, educators not only modernize laboratory education but also contribute to bridging the gap between academic training and the practices of the global scientific community. This study therefore supports the argument that open science should not be restricted to professional researchers but should be cultivated as an integral component of students’ scientific training.

Conclusion

This study explored the integration of international open data platforms into the physics practicum as a means of enhancing students’ scientific and professional competencies.[15] The findings clearly indicate that embedding open science principles within laboratory education not only strengthens traditional learning outcomes but also equips students with the skills required for participation in the global scientific community. Quantitative results demonstrated significant gains in data literacy, digital competence, and collaborative research skills among students who actively engaged in open data practices. Qualitative evidence further confirmed that students developed greater motivation, a heightened sense of responsibility, and stronger awareness of ethical considerations related to data sharing. Together, these outcomes suggest that open data integration transforms the physics practicum into a dynamic, competence-based, and internationally connected educational experience.[16]

The novelty of this research lies in extending open science practices beyond professional research contexts and into undergraduate and graduate education. By positioning students as active contributors to open repositories such as Zenodo, Figshare, and OSF, the physics practicum becomes not only a platform for learning fundamental physical concepts but also a gateway to cultivating twenty-first century competencies. While challenges remain—particularly regarding data standardization, technical infrastructure, and ethical safeguards—the benefits of this approach significantly outweigh its limitations. Future research should focus on developing comprehensive pedagogical models, exploring interdisciplinary applications of open data in other STEM subjects, and evaluating long-term impacts on students’ career readiness.[17]

In conclusion, integrating open data platforms into physics education provides a powerful strategy for aligning laboratory teaching with global trends in open science and digital education. It represents a meaningful step toward bridging the gap between local learning activities and international scientific collaboration, thereby contributing to the modernization of higher education and the professional development of future scientists and educators.

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