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# METHODOLOGY FOR DEVELOPING STUDENTS′ RESEARCH COMPETENCE BASED ON INTEGRATING PHYSICS EXPERIMENT RESULTS INTO OPEN DIGITAL DATA PLATFORMS

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**Abstract:** This article presents a modern methodological approach to developing students' research competence during the organization of physics courses—specifically, practical physics laboratory sessions—in higher education institutions. The core idea of the research is to move beyond merely retaining results obtained during physics experiments as components of laboratory reports; instead, it proposes transforming them into digital datasets, describing them with metadata, uploading them to open scientific data platforms, and enabling their reuse and comparison with other data.

**Keywords:** physics experiment, physics practicum, research competence, open science, open scientific data, digital data, metadata, inquiry-based learning, digital education, experimental competence.

**Introduction**. In the 21st century, one of the main tasks of higher education, in addition to providing students with ready-made knowledge, is to prepare them as specialists capable of independently searching for, creating, verifying, analyzing and scientifically communicating new knowledge. Especially in the education of natural sciences, including physics, this task is directly related to experimental activity. Because a significant part of physical knowledge is formed through observation, measurement, experimentation, analysis of evidence and mathematical modeling.

Physics laboratory classes create a unique pedagogical environment for involving students in experimental science activities. However, modern physics education research shows that it is not enough to limit the purpose of laboratory classes to strengthening theoretical knowledge alone. Wilcox and Lewandowski showed that the orientation of physics laboratory classes to the development of laboratory skills has a positive effect on students' views on experimental physics. The conducted studies revealed a certain difference between the cognitive activities performed in laboratory courses and real undergraduate research experiments. It was noted that in research activities, processes such as independent formulation of the problem, revision of the solution, use of errors, and ownership of the activity are more common. From this point of view, it is an important pedagogical task to transform physics practicum from a reproductive activity for the student consisting of the sequence “perform an experiment - fill in the table - use the formula - write a conclusion” into a form of small scientific research.

Today, one of the promising directions for solving this problem is the integration of work with open scientific data (open research data) into the educational process. In the open science paradigm, the creation, description, storage, exchange and reuse of scientific data is becoming one of the

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important components of scientific activity. The UNESCO Recommendation on Open Science determines that scientific data, methods, infrastructures and knowledge exchange play an important role in the ecosystem of open scientific knowledge. One of the most important conceptual foundations of scientific data management is the FAIR principles proposed by Wilkinson and co-authors - Findable, Accessible, Interoperable, Reusable. According to them, data should be findable, usable, interoperable with different systems and suitable for reuse.

Applying these principles to physics practicum significantly expands student activity. The student does not just perform the experiment; he forms his experimental data as a scientific dataset, interprets the data structure, indicates units of measurement, records the experimental conditions through metadata, and places the data in an open environment for future use by other researchers or students. Therefore, the purpose of the study is to develop a methodology for developing students' research competence based on the integration of physical experiment results into digital open data platforms and to scientifically substantiate its didactic capabilities.

In physics education, laboratory exercises have long been viewed as a means of consolidating theoretical knowledge in practice. However, modern physics education research shows that the tasks of the laboratory are much broader than this.

A study published in 2025 found that explicit inquiry approaches in physics laboratories in higher education influenced students' understanding of the nature of science. The study involved 208 students and found that the effectiveness of inquiry pedagogy was also related to students' level of scientific thinking. Therefore, to develop research activities in laboratory classes, it is not enough to simply give students an experimental algorithm. They must be given the opportunity to ask questions, formulate hypotheses, design experiments, collect data, assess uncertainty, interpret evidence, and draw scientific conclusions.

The concept of open scientific data is one of the important directions of modern scientific communication. The FAIR principles, developed by Wilkinson and co-authors, have created a universal methodological framework for the management and reuse of scientific data.

The four main components of the FAIR principles are as follows:

- ✓ Findable — information that can be found;
- ✓ Accessible — information that is accessible;
- ✓ Interoperable — data that can interact with different systems;
- ✓ Reusable — data can be reused.

For example, the Zenodo platform allows scientific objects to be assigned DOIs, described with metadata, and indexed in search engines. nFigshare is also one of the open scientific infrastructures designed to store, share, and reuse scientific datasets and other research results. The use of these platforms in the educational process can serve to form a student's culture of working with scientific information.

In addition to reading, analyzing, and interpreting data, the ability to create and document data accurately is becoming an important competency for the modern researcher. Data literacy encompasses the ability to understand, evaluate, analyze, and communicate data scientifically. Recent research on integrating FAIR data management into education also demonstrates the potential for developing data literacy.

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The ACRL Information Literacy Framework for Higher Education, which defines "Research as Inquiry," envisions students understanding research as a process of asking questions, seeking information, evaluating evidence, and creating new knowledge. Therefore, integrating open data into physical practicums can develop not only the digital aspects of research competence, but also the scientific, analytical, communicative, and reflective aspects.

The research methodology is based on the integration of competency-based, activity-oriented, inquiry-based learning, open science, and data-driven educational approaches.

The research involves the use of the following methods:

- ✓ systematic analysis of scientific and pedagogical literature;
- ✓ comparative analysis;
- ✓ pedagogical modeling;
- ✓ observation;
- ✓ interview and questionnaire;
- ✓ experimental tasks;
- ✓ content analysis of students' laboratory reports;
- ✓ expert evaluation of datasets;
- ✓ diagnosing competency levels;
- ✓ mathematical and statistical analysis.

A central principle of research methodology is to view the result of an experiment not as a final product, but as an object of scientific data that can be used for further research.

The laboratory session is organized as follows:

Problem → hypothesis → experiment → data → digitization → analysis → metadata → open dataset → reuse → scientific conclusion.

This process moves the student's work from simple laboratory work to the main stages of scientific research.

As part of the research, an author's methodological model called RE-DATA is proposed.

RE-DATA = Research – Experiment – Digitalization – Analysis – Transfer – Assessment

R — Research: defining a research problem

Instead of giving the student a ready-made laboratory algorithm, a research question is proposed.

For example: "How does a change in temperature affect the results of an experiment when determining the coefficient of viscosity of a liquid?"

The student: identifies the problem; formulates a scientific question; searches for available theoretical information; develops a hypothesis.

E — Experiment: physical experiment: The student plans and performs an experiment.

At this stage: measuring instruments; experimental conditions; measurement sequence; repeated measurements; measurement errors are determined.

D — Digitalization: digitization

The resulting data is converted into an electronic dataset.

This saves not only the final calculated value, but also the raw experimental data.

A — Analysis: data analysis

The student: defines the mean value; standard deviation; absolute and relative error; measurement uncertainty; graphical relationships; mathematical model parameters.

It also compares the results obtained with theoretical values and datasets from other groups.

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T — Transfer: integration into an open platform: The finished dataset is placed on an open scientific data platform.

At this stage, the student creates metadata elements for the dataset, such as: name; author; description; keywords; date; experimental conditions; units of measurement; methodology; devices used; file format; license.

Zenodo allows you to store data as scholarly objects through metadata, files, and persistent identifiers, including DOIs.

A — Assessment: evaluation and reflection

At the final stage, the student:

- ❖ evaluates his/her own experience;
- ❖ analyzes data quality;
- ❖ identifies the source of errors;
- ❖ assesses the reusability of the dataset;
- ❖ draws a scientific conclusion.

To test the RE-DATA model in practice, you can use the physics lab "Determining the viscosity coefficient of a liquid using the Stokes method."

Preparatory Stage - Students are given the following research problem:

“How does changing experimental conditions affect the accuracy of determining the viscosity coefficient of a liquid?”

Students are divided into small groups. Roles in the group:

- ▪ Experiment designer — experiment designer;
- ▪ Measurer — measurer;
- ▪ Data analyst — data analyst;
- ▪ Data curator — responsible for datasets and metadata.

2. Experimental Stage - Students collect experimental data by repeatedly measuring physical quantities.

At this stage, the teacher does not provide a ready-made result, but acts as a methodological guide.

Student:

1. records the experimental conditions;
2. stores raw data;
3. repeats measurements;
4. identifies suspicious values;
5. records sources of error.

3. Digitization stage: The results are converted into a spreadsheet. This approach builds the student's data management competence.

4. Open Data Stage : The student prepares the finished dataset for posting on an open platform.

This process is based on the FAIR principles: Discoverability → Usability → Interoperability → Reusability. The FAIR principles are aimed at improving the discoverability, usability, and reusability of data.

5. Reuse phase: The most important difference in the methodology is that the work does not end once the dataset is deployed. Then the next group:

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1. downloads the previous group dataset;
2. compares with his own experience;
3. identifies differences;
4. explains the reasons for the differences;
5. formulates a new scientific question.

As a result, a continuous research cycle is formed in the form of: Group 1 experiment → Group 2 research → new dataset → new scientific question.

CRITERIA FOR ASSESSING RESEARCH COMPETENCE

Research competence five structural component based on evaluation offer is being done .

Motivational - goal-oriented component - Student : scientific to the problem interest ; research purpose understanding ; independent to search readiness ; experiment to the result responsible attitude is evaluated .

2. Cognitive component in this student : physicist theory explanation ; research question to formulate ; hypothesis previously push ; physics model choice with described .

3. Experimental - practical component – in this student : experiment planning ; measuring from the means use ; repetition measurements done increase ; experiment to safety compliance to make ; mistakes identification skills manifestation does .

4. Digital - analytical component in this student : information digitization ; electronic dataset create ; graphic and diagrams compilation ; statistical analysis ; data uncertainty calculation ; metadata create ; open to the platform information placement to the ability has to be need .

Communicative - reflexive component - in this student : research the results presented to add ; dataset explanation ; other research with comparison ; scientific conclusion to release ; to activity assessment abilities manifestation will reach .

This transformation expands the didactic possibilities of physics practicum. First, the student begins to see the result of the experiment as an object of scientific information, not a simple “answer”. Second, working with metadata develops the student's culture of data documentation. Third, reusing open datasets develops the student's skills in comparative analysis, evaluation of evidence, and formulation of a new research question. Fourth, physics laboratory exercises become closer to scientific research activities.

This finding is also consistent with existing research on inquiry-based labs, which have shown that inquiry labs improve scientific thinking and experimental design skills.

On this basis, the expected educational effect of the RE-DATA model is reflected in the integration of the following competencies: experimental competence + data literacy + digital competence + critical thinking + scientific communication = research competence.

The results of the study show that linking physics practicum with digital open data creates a new pedagogical opportunity for the formation of students' research competence. In traditional laboratory classes, students often perform experiments based on an algorithm given by the teacher. This may limit the ability to independently formulate a research question, develop an experimental design, or apply the data in other studies in the future. Research on open-ended laboratory activities has shown that giving students more autonomy is associated with a better understanding of the nature of experimental physics.

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The RE-DATA model solves this problem by changing the final stage of the laboratory process. That is, the laboratory does not end with a "conclusion", but continues with the creation and reuse of an open dataset. This process also changes the student's perception of scientific activity. It is through practical activities that the idea that scientific research is not just about "achieving a result", but also about the process of generating, documenting, sharing, critically evaluating and reusing data is learned.

**ADVANTAGES OF THE SCIENTIFIC-METHODICAL MODEL**

The main advantages of the proposed methodology are:

The first advantage is continuity. Experimental data is not lost when the lab work is over.

The second advantage is reusability. One group's data can be used by another group in their research.

The third advantage is the research environment. The student will gain experience working with real scientific data.

The fourth advantage is digital competence. Working with spreadsheets, graphs, statistical analysis, and datasets will develop.

The fifth advantage is scientific communication. The student learns to present his results in a format that other users can understand.

The sixth advantage is interdisciplinary integration. Elements of physics, mathematics, computer science, and scientific methodology are combined into a single activity.

In modernizing physics practicum, it is not enough to equip laboratory exercises only with digital tools. An important task is to bring the student's experimental activity closer to scientific research activities. From this point of view, integrating the results of physical experiments into digital open data platforms creates a promising methodological opportunity for developing students' research competence. The RE-DATA model developed as part of the study — Research, Experiment, Digitalization, Analysis, Transfer, Assessment — involves transforming a physical experiment into a full research cycle. In the model, the student performs activities ranging from identifying a research problem to designing an experiment, digitizing data, statistical and physical analysis, creating metadata, integrating the dataset into an open scientific platform, and reflexive evaluation of the results. The main pedagogical innovation of the RE-DATA model is that the result of a laboratory experiment is considered not only as a report to be submitted to the teacher, but as a digital dataset intended for scientific reuse. As a result, laboratory exercises are transformed from a closed educational activity into an open scientific and educational activity.

The complex development of the motivational-purposeful, cognitive, experimental-practical, digital-analytical, and communicative-reflexive components of research competence is an important pedagogical result of this methodology.

Thus, the integration of physical experiment results into digital open data platforms should not be considered digitization itself, but rather a pedagogical technology that serves to transform the student into a subject who creates, analyzes, documents experimental data, and produces scientific knowledge.

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