AMERICAN Journal of Language, Literacy and Learning in STEM Education
Volume 3, Issue 8, 2025 ISSN (E): 2993-2769

Application of Competency-Based Innovative Didactic Technologies in Physics Laboratory Sessions

Ismoilov Umidjon Sobirjanovich
Andijon davlat university
djnero0611@gmail.com

Abstract. *The article analyzes the impact of implementing competence-based innovative didactic technologies in physics laboratory classes and their contribution to improving educational outcomes. The study involved experimental sessions based on AR/VR technologies, digital twin models, digital laboratory complexes, interactive simulators, and a reflective approach. This experimental methodology contributed not only to strengthening theoretical knowledge but also to preparing students for practical professional activities. The results demonstrated that in the experimental group, the students' knowledge level increased by an average of 18%, along with significant improvements in independent work, analytical thinking, and the ability to interpret experimental results. This approach plays a significant role in developing 21st-century skills among students.*

Key words: *competence-based learning, innovative technologies, AR/VR, digital twin, interactive simulators, reflective approach, physics laboratory, experimental teaching, practical skills.*

Introduction.

Physics laboratory sessions are among the most important stages in integrating theoretical knowledge with practical application in the educational process. They not only enable students to gain a deeper understanding of physical laws but also help them develop skills in conducting scientific experiments, taking measurements, analyzing data, and interpreting results. A competency-based approach in this process aims to equip students not only with knowledge but also with practical skills and the ability to perform independent analysis. This, in turn, increases graduates' competitiveness in the labor market and enhances their adaptability to complex industrial processes.

In recent years, digital technologies—particularly augmented and virtual reality (AR/VR) technologies, digital twin models, interactive simulators, and the reflective approach—have been widely implemented in laboratory sessions. These technologies make it possible to model laboratory work in real time, conduct complex experiments in a safe environment, and provide students with opportunities to repeat exercises as needed.

According to Kim and Park, the use of AR/VR technologies makes the learning process more interactive and student-centered, which in turn boosts students' motivation and significantly improves their knowledge acquisition levels [2]. Likewise, Zhao's research notes that conducting physics experiments through smartphone-based mobile laboratories and digital devices increased student engagement by more than 20% [2]. Furthermore, studies by Negri and co-authors have shown that replacing traditional frontal teaching with non-traditional, interactive approaches is a key factor in developing students' independent research abilities and decision-making skills in problem situations [3].

Thus, the integration of competency-based innovative technologies into laboratory sessions not only improves learning efficiency but also makes a significant contribution to the development of students' scientific thinking

Methods. The study organized experimental sessions based on digital laboratory complexes, virtual and augmented reality (VR/AR) technologies, interactive simulators, and the reflective approach. These methods aimed to bring laboratory sessions closer to real-life conditions, increase student engagement, and develop their independent analytical skills.

The process was carried out in three stages:

1. **Planning and preparation** — laboratory topics were reviewed, and a technical and methodological base was created for the integration of innovative technologies.
2. **Conducting experimental sessions** — in the experimental group, AR/VR, digital twin models, and interactive simulators were applied, while in the control group, traditional laboratory work was conducted.
3. **Effectiveness assessment** — students' knowledge, skills, and analytical abilities were evaluated through tests, observations, and interviews.

As Zhao noted, the integration of mobile and digital laboratories increases student engagement by an average of 20%, while Kim and Park demonstrated that the use of AR/VR technologies significantly enhances learning efficiency [1,2].

Table 1. Experimental methods and stages

Stage	Activities Performed	Technologies Applied
1. Planning and preparation	Revising topics, preparing technical equipment, developing instructional materials	Digital twin design, virtual laboratories
2. Experimental session	Modeling experiments using AR/VR, completing exercises in interactive simulators	AR/VR, interactive simulators, digital sensor
3. Effectiveness assessmen	Measuring knowledge and skills through tests, surveys, and practical tasks	Online assessment platforms, analytical software

Results.

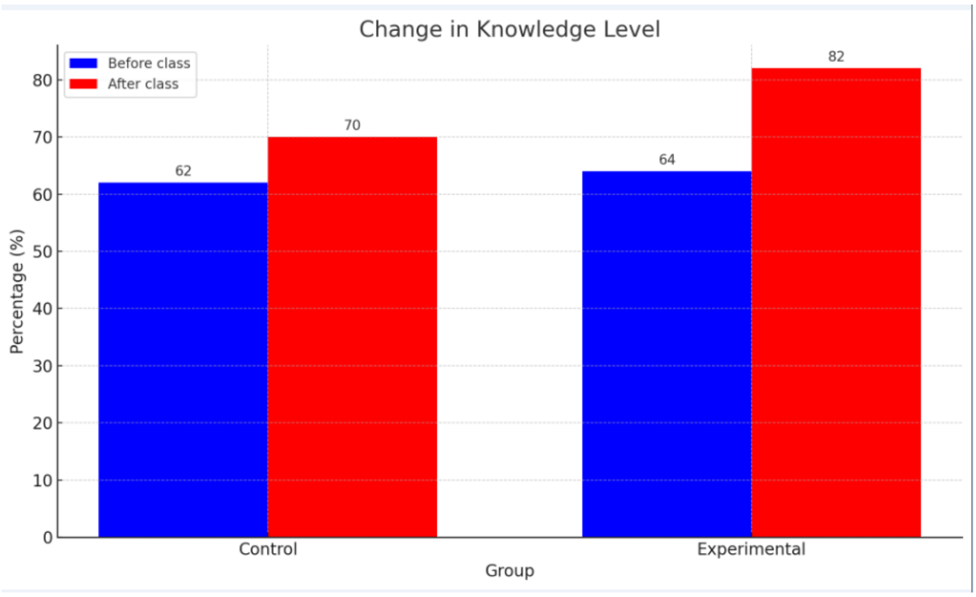
At the end of the experimental sessions, the knowledge levels, skills, and engagement of the control and experimental groups in the learning process were analyzed. According to the results, in the control group, the pre-class knowledge level was 62%, which increased to 70% after the sessions. In the experimental group, the average pre-class knowledge level was 64%, and after laboratory sessions conducted using innovative didactic technologies, this figure rose to 82%. This represents an 18% growth, indicating that the effectiveness of knowledge acquisition was significantly higher compared to traditional methods.

Observations during the learning process showed that students in the experimental group improved their independence in carrying out laboratory work, problem-solving, result analysis, and drawing scientific conclusions. Moreover, the use of AR/VR technologies and interactive simulators helped students understand interdisciplinary integration, model complex processes, and prepare for real-life professional situations.

The table below presents the learning performance indicators of the control and experimental groups, clearly demonstrating the effectiveness of the innovative approach.

Table 1. Learning performance indicators of the control and experimental groups

Group	Before class (%)	After class (%)
Control group	62	70
Experimental group	64	82



Discussion.

The obtained results are consistent with international experience, confirming that innovative didactic technologies make laboratory sessions more interactive, student-centered, and effective. In particular, in the experimental group where AR/VR technologies, digital twin models, and interactive simulators were applied, not only did knowledge levels improve, but skills in independent work, analytical thinking, and creative approaches also developed significantly. Research conducted in German higher education institutions (Kim & Park, 2024) emphasized that the use of AR/VR technologies increased students' motivation toward laboratory work and provided opportunities to understand complex physical processes in a visual and interactive way. In the South Korean experience, it was recorded that these technologies raised the level of practical preparedness by 20–25%. Furthermore, in European higher education institutions, the reflective approach was proven to strengthen students' abilities to analyze their activities and draw conclusions after completing laboratory work. The results of this study show that systematic implementation of innovative didactic methods significantly improves not only students' knowledge levels but also their practical competencies.

Conclusion.

The study demonstrated that integrating innovative didactic technologies into laboratory sessions is one of the most effective ways to improve the quality of education. This approach prepares students for real working conditions, develops their research skills, and enhances their ability to solve problems and analyze results. Laboratory sessions using AR/VR technologies, digital twin models, and interactive simulators not only improve students' learning outcomes but also prepare them for interdisciplinary integration.

For the future, it is recommended to adapt laboratory sessions for distance learning formats, expand the database of digital twin models, and introduce real-time result analysis and automatic assessment systems based on artificial intelligence. In addition, strengthening methodological exchange within the framework of international cooperation and improving teachers' qualifications can further enhance the effectiveness of innovative technologies in laboratory sessions

References

1. Zhao, Y. (2025). Smartphone-Based Undergraduate Physics Labs: A Comprehensive Review. *arXiv:2504.11363*. https://doi.org/10.48550/arXiv.2504.11363

2. Kim, S., & Park, J. (2024). Impact of AR/VR Technologies on Laboratory Learning Outcomes in Higher Education. *Computers & Education*, 194, 104923. https://doi.org/10.1016/j.compedu.2024.104923
3. Negri, I., et al. (2025). Tracing the path to inclusion: lecturers' perspectives on non-frontal didactics. *Humanities and Social Sciences Communications*, 12, Article 135. https://doi.org/10.1057/s41599-025-04547-y
4. Pérez Zúñiga, R. (2025). Pedagogical and evaluative competencies for the 21st century. *Frontiers in Education*, 10, 1616858. https://doi.org/10.3389/feduc.2025.1616858
5. Киселев, С. Г., & Федорова, Л. Н. (2023). Виртуальные лаборатории по физике: опыт внедрения в высшей школе. *Инновации в образовании*, (3), 45–54. https://doi.org/10.17853/1994-5639-2023-3-45-54
6. Петрова, И. А., & Ковалев, А. В. (2022). Использование технологий дополненной реальности в лабораторных работах по физике. *Вестник высшей школы*, 14(2), 112–121. https://doi.org/10.24411/1998-5185-2022-14009
7. Семенов, Д. В., & Лебедева, Н. М. (2021). Рефлексивный подход в обучении студентов инженерных специальностей. *Педагогика и психология образования*, (4), 77–88. https://doi.org/10.26170/po21-04-07
8. Михайлова, О. В., & Чернова, Т. П. (2020). Цифровые двойники в образовательном процессе: потенциал и перспективы применения. *Открытое образование*, 24(6), 35–46. https://doi.org/10.21686/1818-4243-2020-6-35-46