PEDAGOGICAL COMPETENCE IN USING VIRTUAL LABORATORIES IN TEACHING MATERIALS SCIENCE IN HIGHER EDUCATION INSTITUTIONS

Zh.K. Davletmuratov
Karakalpak State University

Abstract

The article examines the theoretical foundations and pedagogical potential of using virtual laboratories in teaching the discipline *Materials Science* in higher education institutions. Virtual laboratories are characterized as effective tools that ensure the safety and accessibility of the educational process while facilitating the development of students' practical skills. Particular emphasis is placed on the role of the teacher and the importance of digital competence in the effective integration of virtual laboratory technologies into the learning process.

Keywords

virtual laboratory, Materials Science, digital learning, engineering education, interactive simulation, teacher's role, teaching methodology.

Introduction

Virtual laboratories can be compared to computer-based scientific simulations that allow students to conduct various experiments on a computer screen. By accessing the Internet, learners can select the required laboratory environment and begin research activities. Such laboratories support the processing of experimental data and contribute to a deeper understanding of scientific processes.

In physics, virtual laboratories enable the study of electromagnetism and Newton's laws; in chemistry, chemical reactions and compounds; in biology, cellular structures; and in computer science, programming and virtual environments.

Advantages of virtual laboratories:

Safety: no hazardous materials or health risks;

Interactivity: freedom to conduct experiments and instantly observe results;

Accessibility: an alternative to expensive equipment and a means of mastering complex topics;

Flexibility: usability regardless of location and time.

The modern higher education system is undergoing an active process of digital transformation. The rapid development of technologies requires educators to master new tools and methods to ensure high-quality learning outcomes. One such innovative tool is the virtual laboratory, which is particularly significant in teaching technical disciplines such as Materials Science.

Materials Science is an interdisciplinary field that studies the structure, properties, processing, and application of materials. Effective teaching of this discipline requires visualization, practical experimentation, and appropriate equipment. Virtual laboratories make it possible to meet these requirements under conditions of limited resources, especially in blended or distance learning formats.

This article reveals the role and professional competence of educators in using virtual laboratories when teaching Materials Science in higher education institutions.

The term *virtual* (from Latin *virtualis*, meaning "potential" or "possible") refers to objects or situations that do not exist physically but can be realized under certain conditions.

The word *laboratory* originates from the Latin *laborare* ("to work") and generally denotes a space equipped for conducting research, analysis, and experiments. At the same time, a laboratory also represents a specific form of instructional activity.

In virtual educational laboratories, learning through modeling promotes students' independent cognitive activity, enhances their understanding of natural phenomena, develops problem-solving skills, and prepares them to apply acquired knowledge in practice.

Thus, the use of virtual laboratories that foster learner autonomy constitutes an integral component of successful implementation of electronic education and computer-based learning traditions [1, p. 21].

Virtual laboratories expand the number of experiments conducted during the learning process and contribute to improving students' academic achievement. The relevance of this research topic is also обусловлено the fact that many educational institutions now possess computer-equipped classrooms and Internet access, enabling the integration of virtual laboratory activities into the curriculum [2].

To operate a virtual laboratory, a computer-based infrastructure is required, including video demonstrations of laboratory experiments, initial parameter datasets, sample selection tools, calculation algorithms, and software that incorporates mathematical modeling and process-specific variables. The operation of a virtual laboratory should replicate the scenario of a traditional laboratory session.

The virtual laboratory program typically follows a four-stage instructional scenario:

1. **Introductory stage** (theoretical background and instructions for laboratory or practical work);
2. **Execution stage** (testing, development of the work scenario, and task implementation);
3. **Report preparation**;
4. **Defense of the completed work**.

It should be noted that although virtual laboratories require significant storage capacity and memory, students are not required to complete all tasks simultaneously. It is sufficient to upload one module and one task designed to master the theoretical component.

In electronic learning environments, instructional and assessment tools are integral elements of the educational process. However, many institutions implementing distance education technologies do not fully consider this aspect. E-learning software should include mechanisms for model construction, model modification, and computational processing.

Advantages of using virtual laboratories:

- reduction in the number of identical physical devices and the absence of maintenance personnel;
- automation of operational procedures;
- broad functional capabilities;
- continuous improvement of equipment in line with methodological advancements.

Virtual laboratories provide students with integrated task systems across disciplines, virtual tools for formalizing process conditions, and problem-solving methods, while enabling educators to systematically monitor and diagnose learning outcomes.

The development of virtual laboratories is a critical issue for the education system, as it enhances the material and technical base of institutions and expands the intellectual potential of users [3, p. 65].

1. Theoretical Foundations of Using Virtual Laboratories in Education

1.1. Concept and Types of Virtual Laboratories

Virtual laboratories are digital simulation environments that model real laboratory processes and experiments. They include:

- **Simulation-based laboratories**, which allow students to observe experiments without active intervention;
- **Interactive laboratories**, where users actively manipulate models;
- **Augmented Reality (AR) and Virtual Reality (VR) laboratories**, which provide a fully immersive experimental experience.

1.2. Educational Advantages of Virtual Laboratories

- **Accessibility:** students can perform diverse experiments;
- **Safety:** elimination of risks associated with hazardous materials and equipment;
- **Repeatability:** experiments can be repeated multiple times;
- **Individualization:** each student can work independently at their own pace.

2. Specific Features of Teaching Materials Science in Higher Education

2.1. Essence of the Discipline

Materials Science provides engineering students with knowledge of material properties, classification, processing methods, failure mechanisms, and application areas. Understanding these processes requires practical skills traditionally developed through laboratory work.

2.2. Teaching Challenges

- lack of expensive equipment;
- limited availability of material samples;
- insufficient time allocated for practical training;
- inability to conduct experiments under special conditions.

3. The Role of the Teacher in Using Virtual Laboratories

3.1. A New Pedagogical Role

The teacher acts not only as a knowledge transmitter but also as a tutor, facilitator, and instructional designer. This role requires:

- mastery of digital platforms and tools;
- preparation of methodological materials for virtual classes;
- support of students' independent learning activities.

3.2. Teacher Competencies

- **Methodological competence:** adapting courses to virtual formats;
- **Technical competence:** proficiency in platforms such as Labster, PhET, and MOLE;
- **Communicative competence:** organizing feedback and discussions;
- **Reflective competence:** analyzing effectiveness and improving instructional processes.

4. Strategies for Effective Use of Virtual Laboratories in Materials Science Courses

4.1. Curriculum Integration

Virtual laboratories should be embedded in the course structure. For example:

- a theoretical lecture on *Mechanical Properties of Metals*;
- a virtual experiment on hardness testing using the Brinell or Vickers method;
- analysis and discussion of results and errors.

4.2. Project-Based Learning

Students may be assigned to select a material, investigate its properties using virtual laboratories, justify its application field, and prepare a presentation.

4.3. Blended Learning Format

Combining traditional and virtual methods, such as:

- preparation through virtual laboratories;
- conducting real experiments in the university laboratory;
- comparison of results and reflective analysis.

5. Successful Implementation Examples

5.1. International Experience

Institutions such as MIT and Stanford University actively use virtual laboratories in engineering programs. Students work with digital models of crystal lattices, phase transitions, and material microstructures.

5.2. Experience of CIS Higher Education Institutions

At Bauman Moscow State Technical University, VR laboratories have been developed for mechanics and Materials Science courses.

At Satbayev University, a blended learning system incorporating digital simulators has been implemented.

6. Challenges and Solutions

6.1. Limitations

- low level of digital literacy among teachers;
- limited access to licensed platforms;
- resistance to change within traditional pedagogy.

6.2. Recommendations

- organization of professional development courses for educators;
- development of open online laboratories at the national level;
- institutional and governmental support for higher education institutions.

Conclusion

Virtual laboratories are becoming a powerful tool for enhancing the quality of engineering education. In the context of rapid technological development, educators must not only master these tools but also apply them didactically and effectively. The teacher's professional competence plays a decisive role in integrating virtual laboratories into the learning process and ensuring the balanced development of students' theoretical knowledge and practical skills.

Thus, teaching Materials Science through virtual laboratories is based on pedagogical competence, technical support, and advanced methodological approaches.

References

1. Ismoilova, M. N., & Murodova, G. I. (2016). Tasks and possibilities of virtual laboratory classes in physics education. *Scientist of the XXI Century*, 4–3(17).
2. Asanova, Zh. K., & Yarovaya, E. Yu. (2022). Development of methodology for highly effective use of virtual laboratories in inorganic chemistry. *Universum: Psychology and Education*, 3(93).
3. Nikulina, T. V., & Starichenko, E. B. (2016). Virtual educational laboratories: principles and possibilities. *Information and Communication Technologies in Education. Pedagogical Education in Russia*, 7.