The Eurasia Proceedings of
Educational & Social Sciences (EPESS)
ISSN: 2587-1730

The Eurasia Proceedings of Educational and Social Sciences (EPESS), 2025

Volume 47, Pages 45-56

IConSE 2025: International Conference on Science and Education

Innovative Technologies in Science Education: Virtual Laboratory Applications

Kadriye Kayacan
Necmettin Erbakan University

Rabia Sultan Gunes-Koc
Ministry of National Education

Abstract: Laboratories are essential environments frequently utilized in fields such as education, engineering, medicine, veterinary sciences, and pharmacy. They are specialized spaces equipped for conducting scientific research, experiments, analyses, and measurements. Traditionally, laboratories are designed and furnished based on the specific needs of their disciplines. However, with advances in technology, virtual laboratories have emerged as a significant alternative, enabling remote experimentation through realistic software simulations. While virtual laboratories do not entirely replace physical ones, they enrich the learning and research process by offering flexibility and accessibility. Virtual laboratories offer several advantages, including cost efficiency, time savings, enhanced collaboration, reduced safety risks by minimizing workplace accidents, and unrestricted access to experiments at any time. Additionally, the ability to repeat experiments multiple times helps reinforce learning. Despite these benefits, virtual laboratories have certain limitations. They may not fully replicate the hands-on experience, can be subject to technical issues, and might limit teacher-student interactions. Moreover, these platforms may not adequately foster social skills development, which is crucial for teamwork-based learning environments. This study aims to explore virtual laboratories across various disciplines, analyzing their features and potential. By providing comprehensive information on the content and structure of these innovative technologies, the research seeks to highlight both the strengths and challenges associated with virtual laboratory applications.

Keywords: Virtual labs, Remote learning, Simulations, Educational tech, Science education

Introduction

Science and technology are two interrelated and complementary concepts that cannot be considered in isolation in today's world. The rapid developments of the 21st century have driven countries into intense competition in technological innovation, making it essential to closely follow and integrate advancements in this field (Şimşek et al., 2008). Particularly, advancements in communication and information technologies have facilitated the rapid production and dissemination of knowledge, while making the effective and efficient use of technology in education a critical necessity (Ünal, 2017). Comprehensive reforms in education systems have mandated the integration of technological resources into teaching and learning processes (Tataroğlu, 2009).

Science education has gained increasing significance globally due to its relevance to essential domains such as health, environment, and energy. Investments in this field are growing, and laboratory practices play a pivotal role in developing students' scientific process skills (Çepni & Ayvacı, 2006). Experimental activities enable learners to explore knowledge through experience, test their understanding, and enhance scientific thinking skills (Korkmaz & Kaptan, 2001).

Modern educational approaches prioritize cultivating individuals who are independent thinkers, creative, and capable of scientific reasoning, rather than focusing solely on knowledge transmission. Therefore, it is crucial to select teaching methods and techniques aligned with both course content and students' needs (Özcan & Kaçar, 2021). Science education, characterized by high interaction with the environment, necessitates methods that reflect this interaction—chief among them being laboratory practices (Çepni et al., 1997).

Laboratory activities are essential for concretizing abstract concepts and facilitating learning through direct experience. These practices significantly contribute to the development of scientific process skills and foster reasoning, critical thinking, and problem-solving abilities (Adey et al., 2000). Moreover, they positively affect students' attitudes toward science (Serin, 2001). However, in many educational institutions, limitations such as inadequate infrastructure, insufficient materials, and difficulties in physical implementation have increased the demand for alternative instructional methods. In this context, digital tools such as computer-assisted simulations and animations offer significant alternatives by allowing students to engage with experimental processes in virtual environments. Virtual laboratories have become particularly prominent during periods of widespread distance education due to their accessible, safe, cost-effective, and flexible structure (Rutten et al., 2012). These platforms allow learners to repeat experiments, engage in inquiry-based learning, and participate actively in scientific processes without the fear of failure. In addition to the field of education, many other disciplines have increasingly utilized virtual laboratories. In medical education, virtual simulations are used to teach anatomy, physiology, and clinical skills—providing safe environments where students can practice procedures without real-world risks. In engineering, particularly in chemical, electrical, and mechanical branches, virtual labs help students simulate complex systems and conduct analytical tasks. Similarly, in pharmacy and veterinary medicine, virtual laboratories offer ethically sound, practice-based learning environments that contribute to developing professional competencies.

Virtual laboratories not only offer advantages in terms of cost, time, and safety but also support active engagement in scientific inquiry (Rutten, van Joolingen & van der Veen, 2012). They enhance motivation, support conceptual learning, and contribute to academic achievement (Honey et al., 2014). Moreover, virtual laboratories can support not only individual learning but also collaborative work. Online platforms allow for group-based experimentation, enabling students to improve communication, task sharing, and social responsibility skills. In interdisciplinary, project-based environments, learners can design joint experiments and share results through digital reporting tools, which contributes to the development of both individual and social competencies.

The COVID-19 pandemic revealed the global necessity for digital learning tools and rapidly accelerated the shift toward online education (Mulenga & Marbán, 2020). During this period, virtual laboratories were effectively implemented in many countries and have continued to be improved in terms of both software and content (Baş, 2022). Virtual laboratory applications provide a learning process that is safe, repeatable, adaptable to individual learning pace, and independent of physical constraints. However, they also pose certain disadvantages such as lack of physical hands-on experience, limited social interaction, and dependence on technical infrastructure (Ma & Nickerson, 2006; de Jong, Linn, & Zacharia, 2013; Ayas & Tatli, 2013). Given the physical constraints of traditional laboratories, virtual laboratories offer important solutions for improving accessibility, particularly in rural areas or under-resourced institutions. These platforms support inquiry-based, hands-on, and experiential learning, thereby contributing to meaningful and lasting educational experiences.

In conclusion, virtual laboratories are increasingly recognized as innovative and complementary tools for developing scientific process skills. Expanding their use, enriching their content, and making them more pedagogically effective in line with technological developments will make them an indispensable component of contemporary science education and interdisciplinary practices.

This study aims to identify and introduce commonly used virtual laboratory tools and applications in science education, with a focus on their pedagogical functions, technological features, and potential contributions to students' scientific process skills and conceptual understanding. Virtual laboratory applications have become essential tools in modern science education, offering interactive and flexible environments for students to engage with scientific concepts. Among the most widely used platforms are PhET Interactive Simulations, Algodoo, JavaLab, ChemLab, Labster, Olabs, BSCS 3D MSS Virtual Microscope These tools vary in terms of features, disciplinary focus, user interface, and accessibility.

Method

This study employs a qualitative, descriptive–exploratory design aimed at directly analyzing and explaining widely used virtual laboratory applications in science education. Seven specific platforms were purposefully selected for in-depth examination: PhET Interactive Simulations, Algodoo, JavaLab, ChemLab, Labster, OLabs, and the BSCS 3D MSS Virtual Microscope. Each application was evaluated in terms of:

- Access mode (open-source, browser-based, licensed),
- Target educational level (elementary, secondary, higher education),
- Types of learning content offered (simulations, interactive tasks, data tools),
- Pedagogical affordances (hypothesis building, variable control, conceptual visualization, etc.)

For each tool, an example learning activity was designed or adapted to illustrate its instructional potential. These sample activities focused on students' acquisition of scientific process skills, problem-solving abilities, and conceptual understanding. Rather than conducting a literature-based review, this study draws from first-hand analysis of each platform's interface and capabilities. It seeks to systematically present their pedagogical functions through use-case scenarios and instructional design elements.

PhET Interactive Simulations

PhET Interactive Simulations (University of Colorado Boulder) provides free, web-based interactive simulations across physics, chemistry, biology, mathematics, and earth sciences. Known for its user-friendly design and visual feedback, PhET supports both individual and classroom learning settings, covering topics from mechanics to molecular biology. In many schools in developing countries, inadequate laboratory infrastructure seriously limits the experimentation and hands-on learning that should be part of science education. This situation prevents students from developing their scientific process skills and life skills through practical application, and makes it difficult for teachers to conduct experiment-based teaching. The PhET Interactive Simulations platform, which was examined in the scope of the research, has the potential to largely compensate for this deficiency.

PhET creates an alternative learning environment for schools that do not have access to physical laboratory equipment by offering students the opportunity to conduct experiments in a virtual environment. Particularly in subjects such as electrical circuits, force-motion relationships, and molecular structure, students can support conceptual learning with interactive applications that are very close to the real experimental process. In addition, the fact that the platform can run on a simple computer with internet access increases its usability in schools with limited resources. Below is a learning outcome and screenshot of an experiment that can be conducted while explaining electrical circuits.

Learning Outcome: Formulating hypotheses about the variables that affect the brightness of a light bulb in an electrical circuit

a) Identifies the variables that affect the brightness of a light bulb in electrical circuits.
b) Determines the change in light bulb brightness by changing the number of batteries and light bulbs in a cause-and-effect relationship context.
c) Identifies the dependent, independent, and controlled variables in bulb brightness.
ç) Controls the number of batteries and bulbs as independent variables.
d) Makes statements about how bulb brightness changes depending on the number of batteries and bulbs in different electrical circuits.

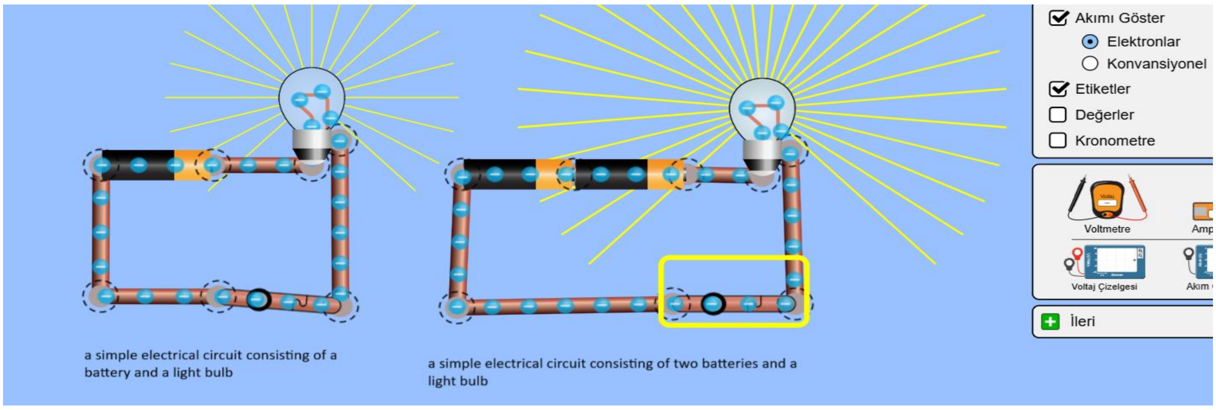

Figure1. A simple electrical circuit setup in PhET simulation showing battery impact on lamp brightness.

In this experiment (Figure 1), students will observe the effect of the number of batteries on the brightness of a lamp in a simple electrical circuit.

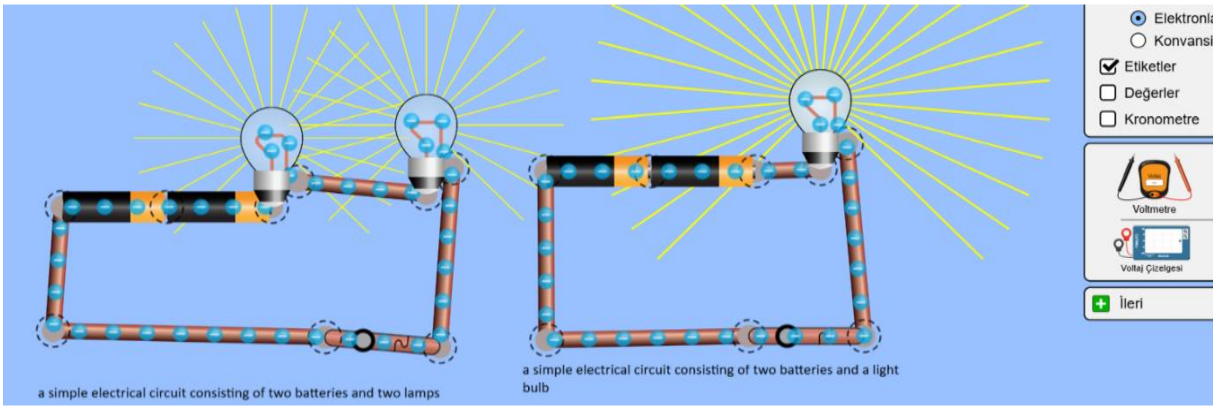

Figure 2. A simple electrical circuit setup in PhET simulation showing lamps' number impact on lamp brightness

In this experiment (Figure 2), students will observe the effect of the number of lamps on the brightness of the lamp in a simple electrical circuit. In this respect, PhET is not only a simulation of experimental learning, but can also be considered a digital educational tool that provides equal opportunities. Teachers can use this platform to continue developing students' basic scientific skills, such as hypothesizing, observing, controlling variables, and drawing conclusions, even when physical experiments cannot be conducted.

Algodoo

Algodoo is an innovative digital learning tool that enables students to engage directly and interactively with physical concepts, particularly in educational environments where experimental kits are limited or unavailable. The software provides users with a blank virtual workspace—similar to a smart board—where both teachers and students can build their own simulations from scratch. Within this space, learners can freely draw objects, assign them physical properties such as mass, friction coefficient, velocity, and direction, and observe their interactions in real time. One of Algodoo's key strengths lies in its adherence to real-world physical laws. Simulations operate under authentic physics principles, including gravity, force, momentum, and energy conservation. For example, students can observe the effect of gravity in projectile motion, compare the behavior of objects on frictionless versus frictional surfaces, or explore momentum transfer in collisions through hands-on experimentation.

In this way, Algodoo not only supports students' conceptual understanding of core physics topics, but also contributes significantly to the development of scientific process skills (such as hypothesis generation, identifying variables, prediction, testing, and interpretation), cause-and-effect reasoning, and systems thinking. Moreover, the ability to design and manipulate simulations transforms learners from passive observers into active participants, fostering an inquiry-based, constructivist learning experience grounded in exploration and individual meaning-making.

Example Activity: Exploring the Effect of Surface Friction on Sliding Motion

In this activity, students draw an inclined plane and place a box on it within the simulation environment. The sliding motion of the box occurs automatically based on the surface friction and the angle of the incline. Students can experiment with different values of surface friction to observe how it influences the speed and movement of the box as it slides down. By testing various scenarios, students develop an intuitive understanding of the relationship between friction and motion, and how friction affects the acceleration and velocity of objects on inclined surfaces. A screenshot of this activity is shown Figure 3.

Through this activity, the student has the opportunity to develop scientific process skills by experiencing steps such as forming hypotheses, making observations, collecting data, and analyzing results. Additionally, the student strengthens critical thinking by questioning the effects of different variables and gains the ability to interpret outcomes. By experimenting with various scenarios in the simulation, problem-solving skills are enhanced while learning to use digital tools effectively. At the same time, the student gains a deeper understanding of fundamental physics concepts such as force, friction, motion, and speed through direct experience. The activity also provides important learning in experimental design by enabling the student to control variables and compare results.

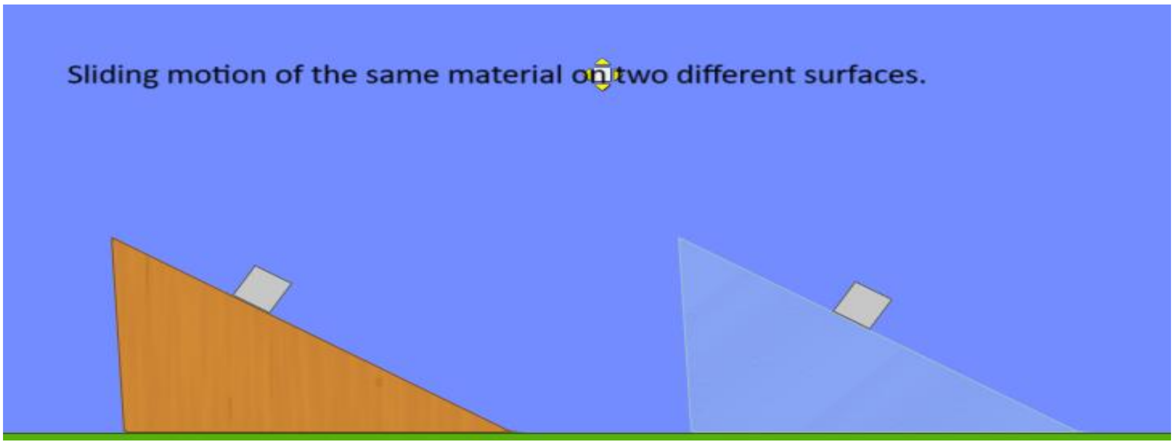

Figure 3. Surface friction affecting the sliding motion in Algodoo.

JavaLab

Javalab is a comprehensive Java-based software platform designed to facilitate mathematical and physical modeling, primarily at the university level. It enables users to construct, simulate, and visualize complex mathematical functions, dynamic systems, and physical phenomena in an interactive and intuitive environment. JavaLab supports a wide range of functionalities, including symbolic computation, numerical analysis, and the graphical representation of functions in both two- and three-dimensional spaces.

The platform's scripting capabilities allow for flexible model development, empowering students and educators to customize simulations tailored to specific educational objectives. By bridging theoretical concepts with visual and practical experimentation, JavaLab enhances conceptual understanding in fields such as calculus, physics, and engineering. Despite its powerful features, JavaLab requires a properly installed Java Runtime Environment (JRE) to operate, which may necessitate additional setup steps. This dependency on Java can sometimes pose accessibility challenges, particularly for users unfamiliar with Java configurations. Nevertheless, once installed, JavaLab serves as a robust tool for interactive learning and research, fostering deeper engagement with scientific and mathematical concepts.

Example Activity: Observing Kinetic, Potential, and Total Energy Changes in a Rollercoaster Simulation

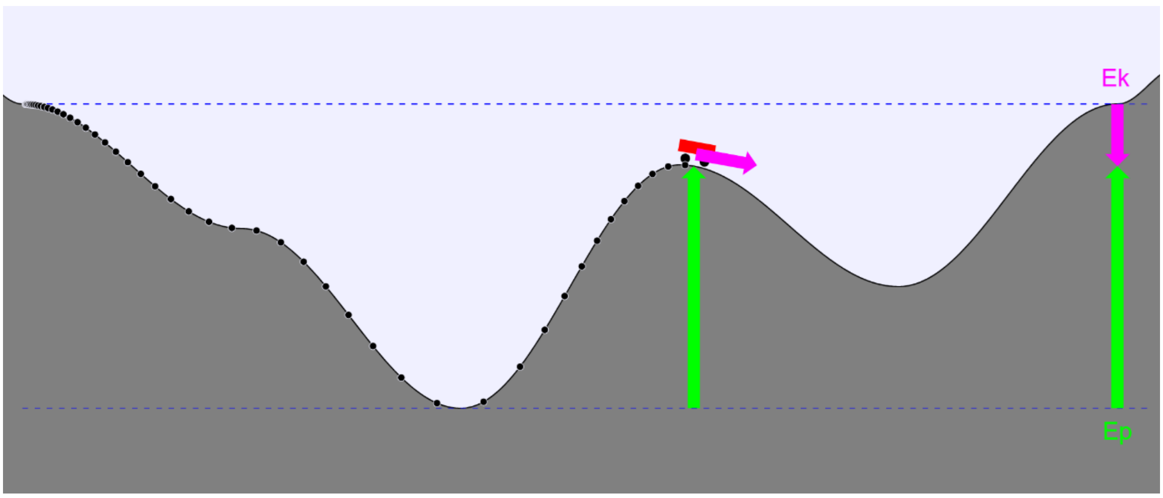

Figure 4. Energy transformations in a rollercoaster simulation using JavaLab

In this activity, students use JavaLab to simulate a rollercoaster car moving along a track with hills and valleys. The simulation allows them to observe how the car's energy changes as it travels. At the highest points of the track, the car has maximum potential energy due to its elevated position. As it descends, potential energy is converted into kinetic energy, increasing the car's speed. Conversely, when the car climbs back up, kinetic energy decreases while potential energy increases. Throughout the motion, students can monitor the total mechanical energy of the system, which remains nearly constant if friction is neglected. By analyzing the energy graphs during the simulation, students gain a clear understanding of energy transformation and conservation in dynamic systems like rollercoasters. A screenshot of this activity is shown in Figure 4.

ChemLab

ChemLab is a sophisticated virtual laboratory simulation platform designed to support chemistry education by providing a safe, interactive environment where students can conduct a wide range of chemical experiments. This platform enables learners to perform fundamental laboratory procedures such as chemical reactions, titrations, and solution preparations without the risks and constraints associated with physical laboratories. By simulating realistic laboratory conditions and instrumentation, ChemLab facilitates experiential learning and reinforces conceptual understanding of chemical principles.

In the context of science education, ChemLab offers significant pedagogical advantages, including the ability to repeat experiments multiple times, manipulate variables precisely, and observe immediate outcomes, thereby fostering scientific inquiry and critical thinking skills. Additionally, ChemLab supports differentiated learning by accommodating various educational levels and learning paces. While some versions of ChemLab are freely accessible, others require licensing or subscription depending on the software provider and institutional agreements. Despite these considerations, ChemLab stands out as a valuable tool in modern chemistry education, bridging theoretical knowledge with practical application through virtual experimentation.

Example Activity: Investigating the Effect of Liquid Volume on Heating Time Using ChemLab

In this activity, students use the ChemLab virtual laboratory to explore how the volume of a liquid affects its heating time. By selecting different amounts of a chosen liquid, such as water, students simulate heating the liquid using a virtual Bunsen burner or hot plate. As the simulation runs, students observe how varying the liquid volume influences the duration required to reach a specific temperature. They record the heating times for each volume and analyze the relationship between the amount of liquid and heating efficiency. Through this experiment, students develop a practical understanding of thermal energy transfer and the factors that affect heating processes. The activity also promotes skills in experimental design, data collection, and scientific analysis within a safe and controlled virtual environment. Below is a screenshot related to this example activity.

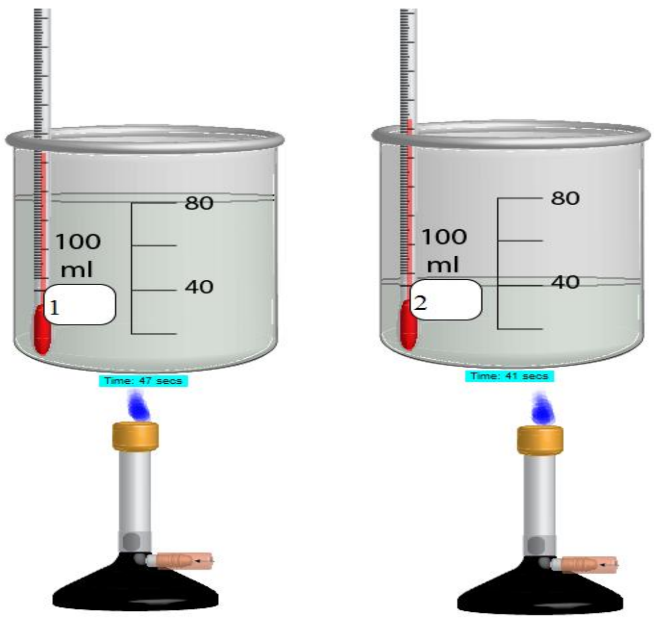

Figure 5. Investigating the effect of liquid volume on heating time using ChemLab virtual laboratory

In this activity, students will observe that the amount of substance affects the rate of temperature change. Beaker 1 contains 80 ml of water, while Beaker 2 contains 40 ml. When heated under the same conditions, the water in Beaker 2 reaches a higher temperature more quickly than the water in Beaker 1. This demonstrates that a smaller volume of liquid heats up faster, even though both receive the same amount of heat energy over time.

Labster: A Comprehensive Virtual Laboratory Platform for STEM Education

Labster is an advanced educational technology platform that provides immersive 3D virtual laboratory experiences across a range of STEM disciplines, including biology, chemistry, physics, medicine, and engineering. Designed to complement and enhance traditional laboratory instruction, Labster offers interactive, scenario-based simulations that allow students to engage in scientific inquiry, perform experiments, and apply theoretical knowledge in a risk-free virtual environment.

One of Labster's defining features is its integration of gamification elements, such as narrative-driven missions, achievement systems, and real-time feedback, which are strategically employed to increase student motivation and engagement. These elements support active learning and help learners develop problem-solving and critical thinking skills in a dynamic and visually rich setting. Labster simulations are structured to follow the scientific method and often include virtual tools, equipment, and data collection systems that closely mimic real-world laboratory experiences. This design enables students to formulate hypotheses, design experiments, test variables, and analyze outcomes—core practices in scientific literacy.

From an instructional perspective, Labster aligns with modern pedagogical approaches such as inquiry-based learning, flipped classroom models, and blended learning environments. Its seamless integration with learning management systems (LMS) like Canvas, Moodle, Blackboard, and Google Classroom allows educators to assign simulations, track student progress, and incorporate virtual labs into existing curricula. While Labster is a powerful tool for expanding access to high-quality laboratory experiences, especially in contexts where physical lab resources are limited, it is generally offered through institutional subscriptions. Access typically requires a license or partnership with a school, college, or university, which may limit availability for individual learners.

In summary, Labster stands out as a pedagogically sound and technologically advanced solution for science education, enabling experiential learning and conceptual understanding through engaging, realistic virtual laboratory environments.

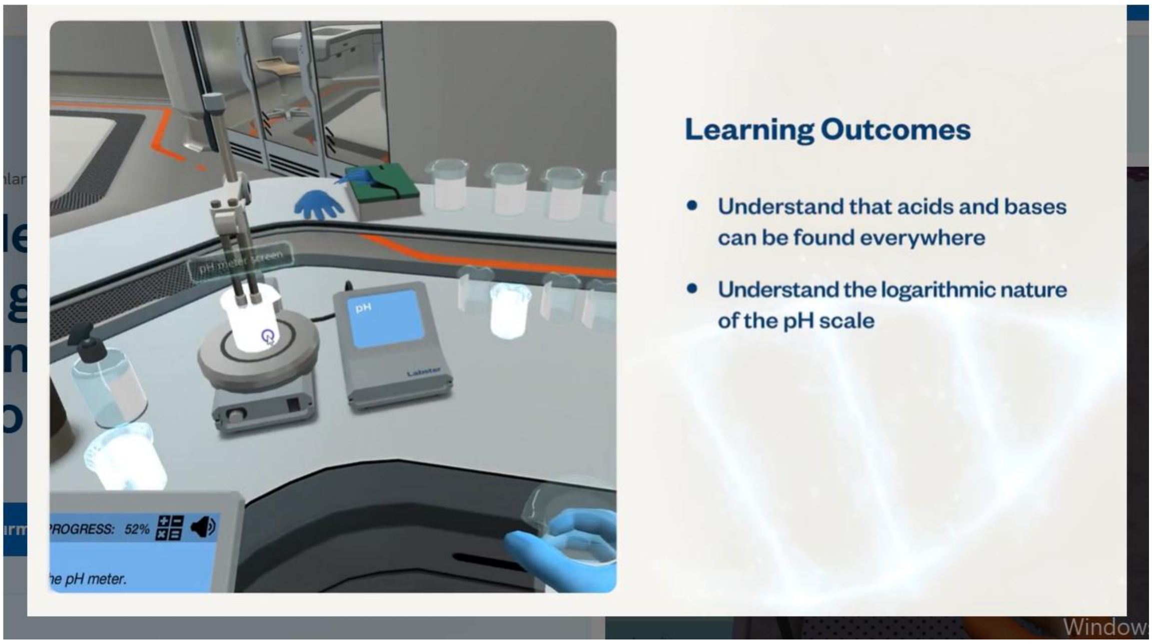

Figure 6. Conceptual exploration of chemical principles in a virtual environment using Labster

This activity promotes conceptual understanding of key chemical concepts through visualization and interaction. It supports inquiry-based learning, encourages the testing of hypotheses, and allows for safe experimentation with potentially hazardous substances in a fully virtual environment.

OLabs (Online Labs for School Experiments)

OLabs (Online Labs for School Experiments) is an interactive, web-based virtual laboratory platform developed by Amrita Vishwa Vidyapeetham in collaboration with India's Ministry of Electronics and Information Technology under the ICT@School initiative. Designed primarily for secondary school students, OLabs provides access to virtual experiments across multiple disciplines, including physics, chemistry, biology, mathematics, and even English grammar, aiming to bridge the gap caused by limited physical laboratory resources.

The platform aligns with national curricula and promotes inquiry-based learning by offering a structured pedagogical design. Each experiment includes theory modules, interactive simulations replicating real-world lab procedures, video demonstrations, and assessment quizzes to facilitate conceptual understanding and scientific process skills. OLabs integrates multimedia and animation to enhance engagement and supports students in practicing observation, data recording, and analytical reasoning.

Accessible freely through standard web browsers without requiring additional software, OLabs is available in multiple regional languages and supports blended and flipped classroom models. Its user-friendly interface and mobile compatibility make it particularly valuable for under-resourced and linguistically diverse educational settings.

By democratizing laboratory access, OLabs not only supplements traditional lab experiences but also enables repeated experimentation, error correction, and independent exploration. Thus, it fosters early development of scientific literacy, critical thinking, and problem-solving skills, contributing significantly to equitable and quality STEM education.

Example Activity: Investigating Temperature Change Over Time

Objective: To observe the cooling process of a hot object and plot its temperature versus time graph.

Theory: A hot object loses heat to its surroundings through conduction, convection, and radiation. The greater the temperature difference, the faster the heat transfer. This process continues until thermal equilibrium is reached.

Experiment: A container with hot liquid (e.g., coffee) is left at room temperature. The temperature of the liquid is measured at regular intervals, and a temperature vs. time graph is plotted.

Observation: The temperature decreases over time and eventually reaches room temperature. Below is a screenshot related to this activity.

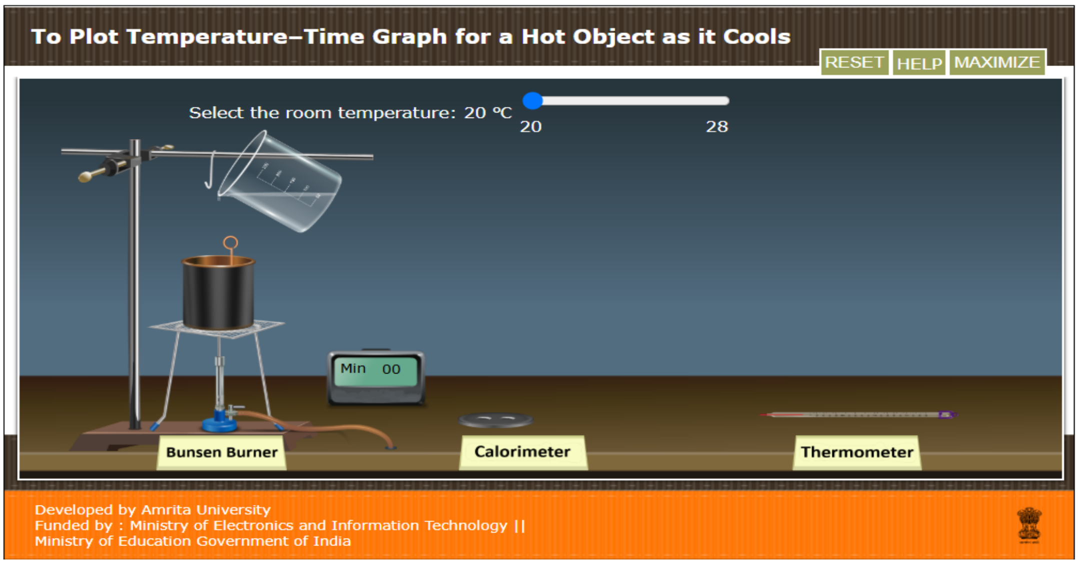

Figure 7. Investigating temperature change over time in a virtual experiment using OLabs

BSCS 3D MSS Virtual Microscope: An Interactive Digital Tool for Enhancing Biological Microscopy Education

The BSCS 3D MSS Virtual Microscope is an advanced, web-based simulation developed by BSCS Science Learning as part of the educational module titled *"A Medical Mystery"*. This interactive platform is designed primarily for middle school students to facilitate the exploration and analysis of biological tissues through virtual microscopy. The application emulates the functionality of a real microscope, allowing learners to engage with three-dimensional tissue samples from various human body systems. By manipulating virtual microscope controls, students can observe cellular structures, focus on different tissue layers, and collect observational data in an immersive environment.

Pedagogically, the tool supports inquiry-based learning by encouraging students to formulate hypotheses, conduct systematic observations, and analyze biological samples in a contextually meaningful manner. It serves as a valuable educational resource particularly in contexts where access to physical laboratory equipment is limited, providing a safe, accessible, and cost-effective alternative to traditional microscopy labs.

Moreover, the integration of this virtual microscope within a broader curriculum fosters conceptual understanding of cell biology and histology, bridging theoretical knowledge with practical skills. The platform's intuitive interface and interactive features enhance student engagement, making it an effective tool for developing scientific reasoning and observational competencies in secondary science education.

Example Activity: Investigating Paramecium Using the BSCS 3D MSS Virtual Microscope

In this activity, students will use the BSCS 3D MSS Virtual Microscope platform to observe the microscopic structure and movements of the unicellular organism *Paramecium*. Students will manipulate the microscope's focus and magnification controls to examine the cell's structure in detail and observe the relationship between the movement of cilia on the cell surface and the organism's locomotion.

During the activity, students will collect observational data about the organism's shape, organelles, and environmental adaptations and compile these findings into a scientific report. This process supports the development of microscopy skills while reinforcing conceptual understanding of cell biology and microorganism motility.

As a result, students will have the opportunity to apply theoretical knowledge practically and engage in experimental inquiry within a virtual laboratory setting, thereby enhancing their scientific process skills in science education.

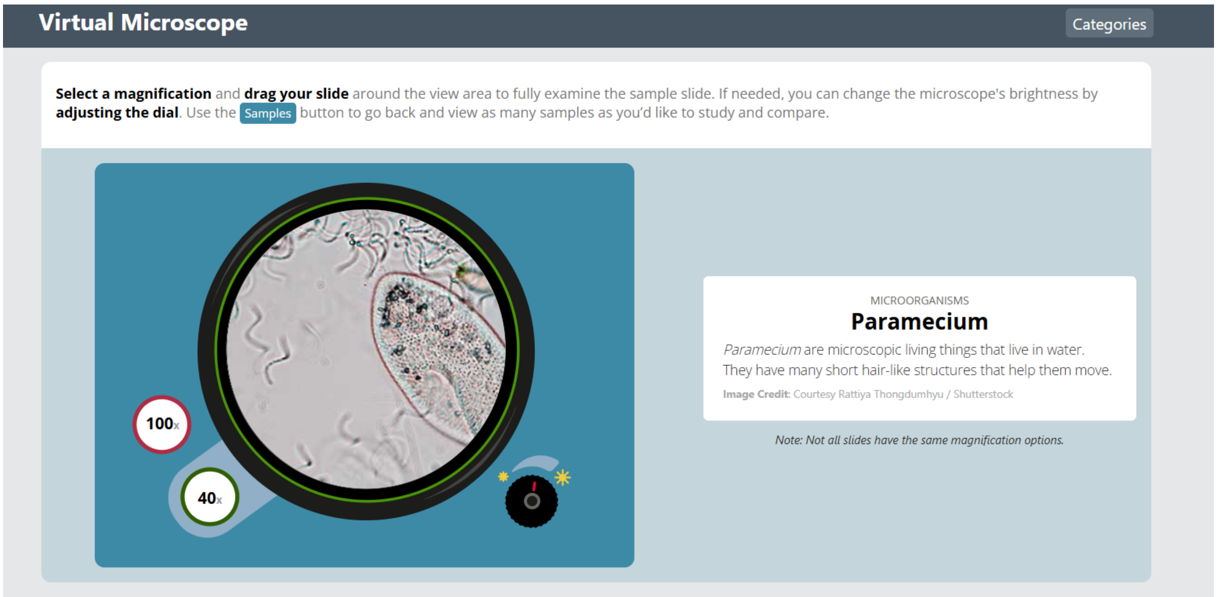

Figure 8. Observing *Paramecium* using the BSCS 3D MSS virtual microscope platform

In situations where students do not have physical access to a microscope, the BSCS 3D MSS Virtual Microscope application provides a valuable alternative by allowing them to examine specimens virtually. Users can adjust magnification levels and manipulate the lighting conditions of the environment to closely observe the structural details of the sample. This flexibility enables learners to simulate real laboratory experiences, enhancing their observational skills and understanding of microscopic structures despite limited access to actual laboratory equipment.

Conclusion and Recommendations

Within the scope of this study, it was observed that virtual laboratories and simulation-based digital learning tools used in science education have the potential to enhance students' academic achievement and learning motivation. The findings align with similar studies conducted in different countries.

Firstly, research on the PhET Interactive Simulations tool has shown that students, especially in physics and chemistry courses, better grasp abstract concepts and participate more actively in the learning process. Banda and Nzabahimana (2022) demonstrated that PhET-supported instruction significantly increased Malawian high school students' academic achievement and motivation in wave and oscillation topics. Similarly, Susilawati et al. (2022) emphasized that PhET improves problem-solving skills and supports motivation. Algodoo software is a visual and interactive simulation tool that supports students' understanding of science concepts through modeling. It stands out by encouraging active participation in the learning process and enhancing creative thinking and problem-solving skills.

Studies conducted in Turkey have shown that Algodoo is particularly effective in teaching physical concepts such as force and motion. In a master's thesis by Özer (2019), Algodoo-based activities prepared for 6th-grade students were found to significantly improve students' academic achievement and design skills. Continuing the applied version of the same research, Özer and Bilici (2021) emphasized that engineering-design based activities conducted with this tool fostered students' progress in problem identification, prototype development, and solution production skills. Moreover, Saylan Kırmızıgül (2021) demonstrated the positive effects of Algodoo-based learning activities on students' science achievement and motivation. In this study, students in the experimental group showed higher academic achievement and more positive attitudes towards science compared to the control group.

Algodoo is also noted internationally as one of the creative teaching tools. Gregorcic and Bodin (2017) stated that Algodoo provides a learning environment that supports creativity in physics lessons and enables the simulation-based understanding of topics such as momentum, friction, light, and energy transformations. Students creating different scenarios and producing their own models deepen conceptual learning and develop original problem-solving approaches. All these studies indicate that Algodoo offers not only a technology-supported tool but also an educationally effective teaching environment in science education. Students' active learning, participation in experiment-design processes, and creative thinking skills significantly improve with such tools.

JavaLab provides a practical learning environment for both teachers and students with simple yet functional simulations in fields such as optics, electricity, motion, chemistry, and biology. JavaLab's user-friendly approach to data-driven experimental modeling and graphical analysis facilitates the teaching process in classroom applications.

ChemLab and Virtual ChemLab applications offer realistic experiment simulations under learning conditions with limited access to laboratory environments. Woodfield et al. (2005) reported that such virtual applications improve students' experimental thinking and chemical analysis skills. Additionally, these tools allow students to observe chemical reactions without any risk regarding laboratory safety.

Labster stands out with its highly interactive and 3D animation-based learning environments. Research on the use of this platform shows increases in students' academic achievement and self-efficacy perceptions. Bonde et al. (2014) reported that using Labster raised students' grade point averages and significantly reduced course dropout rates. OLabs is an effective digital platform developed to provide virtual laboratory experiences in physics, chemistry, biology, and mathematics, especially in infrastructure-limited regions such as India. Studies have reported that OLabs democratizes access to experimental processes and contributes to students' experimental thinking skills (Amrita Vishwa Vidyapeetham, 2021).

BSCS 3D Virtual Microscope enables students to examine tissue samples under different lighting and magnification settings when microscope use is not possible. This tool especially provides experience in biology courses for observing tissues, cells, and microscopic organisms and supports the preparation process before laboratory work (BSCS Science Learning, 2023).

These findings indicate that virtual laboratories are not merely technological necessities but also powerful tools that pedagogically support learning. Such digital applications offer effective methods to develop students' scientific process skills and increase science literacy. Today's new generation of students prefer spending time on screens and using digital environments more frequently. Therefore, the use of virtual laboratories provides an important advantage in attracting students' interest and increasing their learning motivation (Santos & Prudente, 2022). Based on the examined virtual laboratory tools and the results of studies conducted with these tools, the following recommendations can be made:

- *Curriculum Integration*: Systematic inclusion of virtual laboratories in curricula ensures the effective use of technology and allows students to gain regular experience with these tools.
- *In-Service Training:* Professional development programs are essential for teachers and academics to use virtual laboratories pedagogically and effectively.
- *Pedagogical Redesign:* Platforms should be designed to support both individual and collaborative learning, thereby increasing student engagement and the depth of learning.
- *Promotion of Hybrid Models:* The combined use of virtual and physical laboratory experiences leverages the advantages of both environments and offers more comprehensive learning opportunities.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

Funding

* This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Science and Education (www.iconse.net) held in Antalya/Türkiye on November 12-15, 2025.

References

Adey, P., Shayer, M., & Yates, C. (2000). Cognitive acceleration and assessment in science. *Issues in Science Teaching, 81*, 219–233.

Amrita Vishwa Vidyapeetham. (2021). *Online labs for schools (OLabs).* Retrieved from https://olabs.edu.in

Banda, A. M., & Nzabahimana, I. (2022). The impact of PhET simulations on students' performance and motivation in physics: A quasi-experimental study. *Eurasian Journal of Educational Research, 98*, 205–222.

Baş, K. (2022). *Fen eğitiminde sanal laboratuvar uygulamalarının öğrencilerin akademik başarılarına ve fen tutumlarına etkisi* (Unpublished master's thesis). Akdeniz University.

Bonde, M. T., Makransky, G., Wandall, J., Larsen, M. V., Morsing, M., Jarmer, H., & Sommer, M. O. A. (2014). Improving biotech education through gamified laboratory simulations. *Nature Biotechnology, 32*(7), 694–697.

BSCS Science Learning. (2023). *3D virtual microscope overview.* Retrieved from https://bscs.org

Çepni, S., Ayas, A., Johnson, D., & Turgut, F. (1997). *Fizik öğretimi*. YÖK/Dünya Bankası Milli Eğitimi Geliştirme Projesi.

Çepni, S., & Ayvacı, H. Ş. (2006). Laboratuvar destekli fen ve teknoloji öğretimi. In S. Çepni (Ed.), *Kuramdan uygulamaya fen ve teknoloji öğretimi*. Pegem Akademi.

de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*(6130), 305–308.

Gregorcic, B., & Bodin, M. (2017). Algodoo: A tool for encouraging creativity in physics teaching and learning. *The Physics Teacher, 55*(1), 25–28.

Honey, M., Pearson, G., & Schweingruber, H. A. (Eds.). (2014). *STEM integration in K–12 education: Status, prospects, and an agenda for research*. National Academies Press.

Korkmaz, H., & Kaptan, F. (2001). Fen eğitiminde proje tabanlı öğrenme yaklaşımı. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi, 20*, 193–200.

Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: A comparative literature review. *ACM Computing Surveys, 38*(3), 1–24.

Mulenga, E. M., & Marbán, J. M. (2020). Is COVID-19 the gateway for digital learning in mathematics education? *Contemporary Educational Technology, 12*(2), Article ep269.

Özcan, E., & Kaçar, S. (2021). Fen eğitiminde laboratuvar güvenliğine yönelik çalışmaların incelenmesi. *Fen, Matematik, Girişimcilik ve Teknoloji Eğitimi Dergisi, 4*(2), 91–99.

Özer, İ. E. (2019). *6. sınıf kuvvet ve hareket ünitesinde Algodoo temelli etkinliklerin öğrencilerin tasarım becerileri ve akademik başarılarına etkisi* (Unpublished master's thesis). Aksaray Üniversitesi.

Özer, İ. E., & Bilici, S. C. (2021). The effect of engineering design-based Algodoo activities on students' design skills and academic achievement. *Hacettepe University Journal of Education, 36*(2), 301–316.

Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education, 58*(1), 136–153.

Santos, M. L., & Prudente, M. (2022). Effectiveness of virtual laboratories in science education: A meta-analysis. *International Journal of Information and Education Technology, 12*(2), 150–156.

Saylan - Kırmızıgül, A. (2021). Algodoo for interactive learning: Effects on students' achievement and motivation towards science. *Shanlax International Journal of Education, 9*(4), 352–358.

Serin, G. (2001). Fen eğitiminde laboratuvar. In *Yeni binyılın başında Türkiye'de fen bilimleri eğitimi sempozyumu bildirileri*. Maltepe Üniversitesi, İstanbul.

Susilawati, E., Hartono, Y., & Ningsih, E. (2022). The effectiveness of PhET-assisted learning to improve students' problem-solving abilities. *Journal of Physics: Conference Series, 2157*, Article 012098.

Tatli, Z., & Ayas, A. (2013). Effect of a virtual chemistry laboratory on students' achievement. *Educational Technology & Society, 16*(1), 159–170.

Şimşek, A., Özdamar, N., Becit, G., Kılıçer, K., Akbulut, Y., & Yıldırım, Y. (2008). Türkiye'deki eğitim teknolojisi araştırmalarında güncel eğilimler. *Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 19*, 439–458.

Tataroğlu, B. (2009). *Matematik öğretiminde akıllı tahta kullanımının 10. sınıf öğrencilerinin akademik başarıları, tutumları ve özyeterlik düzeylerine etkileri* (Yayımlanmamış yüksek lisans tezi). Dokuz Eylül Üniversitesi, İzmir.

Ünal, B. B. (2017). Web tabanlı uzaktan eğitimin fen bilimleri konularında öğrenci başarısına etkisi. *Uluslararası Türk Eğitim Bilimleri Dergisi, 5*(9), 481–490.

Woodfield, B. F., Catlin, H. R., Waddoups, G. L., Moore, M. S., Swan, R., Allen, R., Bodily, G., & Andersen, T. (2005). The Virtual ChemLab Project: A realistic and sophisticated simulation of inorganic qualitative analysis. *Journal of Chemical Education, 82*(11), 1728–1735.

Author(s) Information

Kadriye Kayacan
Necmettin Erbakan University, Ahmet Keleşoğlu Education Faculty, Konya, Türkiye
Contact e-mail: *kadriyekayacan@gmail.com*

Rabia Sultan Gunes-Koc
Ministry of National Education
Konya, Turkiye

To cite this article:

Kayacan, K., & Gunes-Koc, R. S. (2025). Innovative technologies in science education: Virtual laboratory applications. *The Eurasia Proceedings of Educational and Social Sciences (EPESS), 47,* 45-56.