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VIRTUAL LABORATORIES FOR SCIENCE LEARNING IN THE DIGITAL ERA

Abstrak
Di era digital yang ditandai dengan kemajuan teknologi informasi, pemanfaatan laboratorium virtual menjadi penting dalam meningkatkan kualitas pendidikan sains. Dalam konteks digital ini, laboratorium virtual mempunyai kemampuan untuk menggantikan peran laboratorium nyata dalam menguji teori, hukum, dan konsep ilmiah. Penelitian ini mengeksplorasi berbagai platform laboratorium virtual yang dapat diterapkan pada pendidikan sains. PhET, Chemcollective, dan OLabs adalah platform yang dianalisis dalam artikel ini. Setiap platform memiliki kekuatan dan keterbatasannya masing-masing. Informasi yang diberikan diharapkan dapat menjadi panduan bagi guru dalam memilih platform laboratorium virtual yang selaras dengan tujuan pendidikan sains yang dimaksudkan.
Kata Kunci: Laboratorium Virtual, Pendidikan Sains, Phet, Chemcollective, Olabs.

Abstract
In the digital age marked by advances in information technology, the utilization of virtual laboratories has become crucial in enhancing the quality of science education. In this digital context, virtual laboratories have the capability to replace the role of real laboratories in testing theories, laws, and scientific concepts. This study explores various virtual laboratory platforms that can be applied to science education. PhET, Chemcollective, and OLabs are the platforms analyzed in this article. Each platform has its own strengths and limitations. The information provided is expected to serve as a guide for teachers in selecting the virtual laboratory platform that aligns with the intended objectives of science education.
Keywords: Virtual Laboratory, Science Education, Phet, Chemcollective, Olabs.

INTRODUCTION

Natural science is a branch of knowledge rooted in natural phenomena. These natural phenomena become valuable knowledge when approached with scientific methods and appropriate attitudes. Through the application of scientific methods, the acquired knowledge can be applied for the benefit of humanity. Natural science, as a subject, emphasizes the process rather than the outcomes, providing students with opportunities to explore their potential. Therefore, natural science learning should ideally employ a naturalistic inquiry approach to stimulate critical thinking, work skills, and a scientific attitude. In this context, natural science education should portray the characteristics of scientific products, scientific processes, and scientific attitudes. The development of these three aspects is expected to enhance natural science education, offering direct learning experiences through the application of process skills and a scientific attitude (Fatimah, 2014; Nurmala et al., 2021; Wahyuni, 2022; Zamil & Udyaningsih, 2021)

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Learning the natural sciences cannot proceed without involving laboratory activities. Natural sciences laboratory experiments are an integral part of the learning process, involving a series of experiments conducted by students with the aim of testing and discovering scientific concepts. Natural sciences laboratory experiments provide students with the opportunity to conduct experiments and analyze data according to the objectives of the experiments. Through these experiments, students can directly observe natural phenomena through hands-on investigations. Laboratory activities in the natural sciences play a crucial role in science education, assisting students in discovering and explaining key principles (Darwis & Hardiansyah, 2021; Lutfi & Hidayah, 2017; Widodo et al., 2016). Unfortunately, the implementation of natural sciences laboratory experiments in schools is often hindered by a lack of facilities and infrastructure, as well as the limited human resources managing the laboratory activities. This results in students' low interest in science education, a lack of understanding of scientific concepts, and the insufficient development of 21st-century skills and scientific literacy (Hakim et al., 2020; Hikmah et al., 2017; Rizal et al., 2018).

One alternative option to address these challenges is to replace physical laboratory experiments by utilizing simulation experiments conducted through computers or laptops, known as virtual laboratories. Virtual laboratories are the outcome of computer technology development in the form of interactive multimedia objects designed to simulate laboratory experiments digitally as a learning medium. A virtual laboratory serves as a simulation platform for conventional laboratory activities accessible through computers, devices, consoles, and virtual reality tools. Through virtual laboratories, students can observe the steps of experiments as if they were conducting the experiments themselves. The advantages of using virtual laboratories include the enhancement of critical thinking skills, increased student motivation, active student engagement in the learning process, improvement of scientific process skills, and the development of a scientific mindset among students (Arda, 2022; Basuki, 2023; Bogar et al., 2023; Meilina et al., 2023; Yuliastrin et al., 2022).

Various virtual laboratory platforms are available for use in science education. Therefore, studying the advantages and disadvantages of these available virtual laboratory platforms is crucial for teachers. This understanding is essential for teachers to select a platform that aligns with their educational goals and desired teaching strategies.

METHOD

In this literature review process, the study employed the narrative review method. The source articles analyzed were sourced from Google Scholar using the keywords "virtual laboratory”, and “natural science learning”. A total of 33 articles were identified and screened, ultimately resulting in the analysis of 2 international journal articles and 31 national journal articles in depth.

RESULTS AND DISCUSSION

The role of virtual laboratories in natural science learning is highly significant, particularly in overcoming the limitations of laboratory facilities in schools. Natural science, as a subject at the middle school level, often involves experiments or practical work to enhance students’ skills. However, not all schools have adequate laboratory facilities. Moreover, the COVID-19 pandemic has restricted practical activities in schools, prompting the use of virtual laboratories as an alternative learning method at home (Anfa et al., 2021; Swandi & Rahmadhanningsih, 2021).

A virtual laboratory is an interactive multimedia-based software platform that simulates real laboratory activities. Users can experience laboratory activities as if they were in a real lab through a computer or other electronic devices. In the context of science learning, virtual laboratories not only provide a solution to facility-related problems but also play a vital role in proving theories, laws, and scientific concepts (Bogar et al., 2023; Bunyamin et al., 2021; Nurfidah, 2021).

The implementation of virtual laboratories has several advantages, including enhancing students' understanding of complex materials, integrating 21st-century skills, visualizing abstract concepts concretely, and boosting students’ confidence. Additionally, virtual laboratories improve students’ literacy in the fields of technology and information communication (ICT), cultivate critical thinking skills, and enhance learning outcomes in affective aspects. However, there are drawbacks to using virtual laboratories, such as limited interaction and collaboration among students, as well as limitations in applying formulas or calculations. Furthermore, the use of virtual laboratories cannot replace the real experience of using actual tools and chemicals, which can reduce students' overall understanding. Therefore, even though virtual laboratories provide a practical solution, improvements and adjustments are still necessary to fully replace the hands-on experience in a real laboratory (Gunawan et al., 2017; Mirdayanti, 2017; Muhajarah & Sulthon, 2020; Nirwana, 2011).

Physics Education Technology (PhET): Interactive Learning Transformation in Physics

Physics Education Technology (PhET) is an interactive simulation platform founded in 2002 by Nobel laureate Carl Wieman from the University of Colorado in Boulder, USA. PhET is not just a learning tool; it is a research-based innovation that integrates everyday phenomena with students' scientific knowledge. This platform can be accessed online through the internet or even used offline for free via its official website, https://phet.colorado.edu. Users also have the option to download simulations in HTML file format and share them on social platforms such as Google Classroom, Facebook, and Twitter (Arda, 2022; Basuki, 2023; Bogar et al., 2023; Darwis & Hardiansyah, 2021; Dewa et al., 2020; Hastuti, 2021; Hikmah et al., 2017; Riantoni et al., 2019).

Figure 1. The main interface of the PhET website

With PhET, teachers and students can transform abstract physics concepts into something more tangible through computer-based animations. PhET offers 159 interactive simulations that can be translated into 109 languages, ensuring global accessibility. In the "simulations" menu, users can explore various simulations, including physics simulations. By clicking on "physics" (Figure 2), users can select the desired physics simulation (Figure 3) and explore motion (Figure 4) and 3D shapes presented in the simulation (Figure 5).

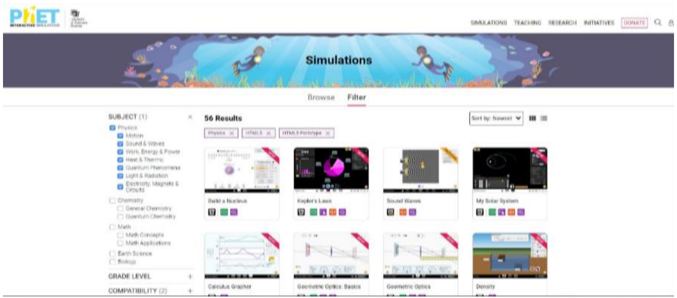

Figure 2. Variety of simulations available in the physics subject

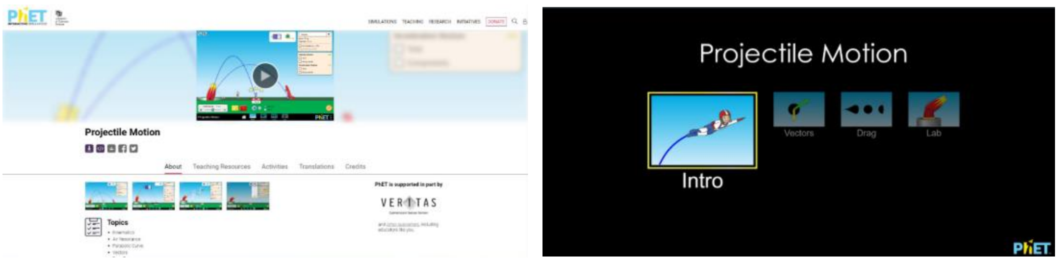

Figure 3. The interface of one simulation topic dan The interface of projectile motion

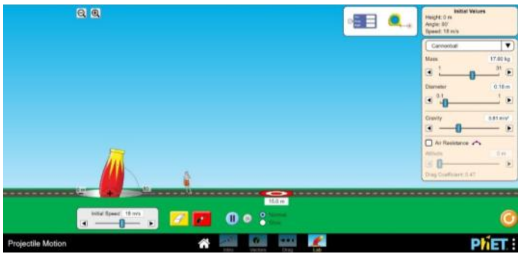

Figure 4. The laboratory work interface on PhET

With its user-friendly interface and diverse range of simulations, PhET provides an inspiring learning tool that changes how students comprehend the world of physics. It turns learning into a memorable and practical experience, reshaping the way education is perceived.

Chemcollective: Online Chemistry Laboratory Simulation

In the context of scientific research, Chemcollective is a virtual laboratory that offers simulations of conventional chemistry experiments through an online platform. The development of this site is undertaken by Carnegie Mellon University and involves simulations based on laboratory apparatus. This resource can be accessed at www.chemcollective.org and is accompanied by digital reading materials available online. Chemcollective creates a highly concrete learning experience with simulations that closely resemble the atmosphere of real experiments without the risks associated with laboratory errors (Hakim et al., 2020; Ningsih et al., 2019)

The main interface of Chemcollective, as depicted in Figure 6, provides an overview of the virtual laboratory concept and various features explaining how to use Chemcollective. The main page also showcases different subject topics (Figure 7), which can be further explored by clicking, as seen in Figure 8. Here, users can select sub-topics for online simulation experiments.

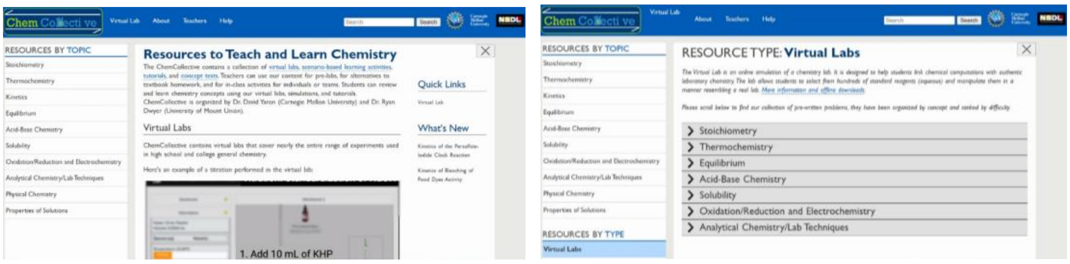

Figure 5. The main interface of chemcollective and The subject topics of virtual labs in chemcollective

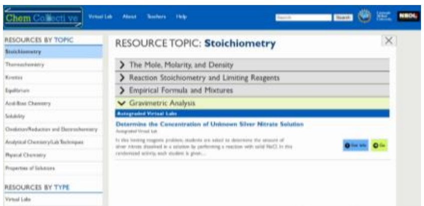

Figure 6. Sub-topics for online simulation experiments

When users choose a specific topic to practice and click the "go" icon, the online experiment page, as shown in Figure 9, appears. Figure 9 displays a virtual workspace equipped with various tools and materials necessary for the experiment on the selected topic. Additionally, other features are provided, such as the ability to edit the workspace by adding or removing tools and watching tutorial videos by clicking the help option. Thus, Chemcollective provides a gateway to a deep and secure chemistry experiment experience through an online platform.

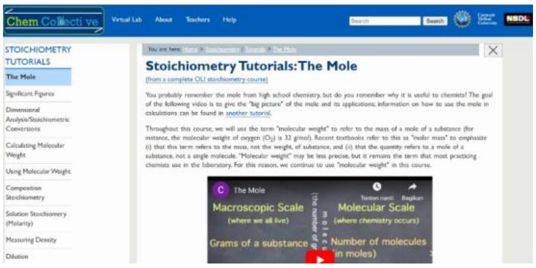

Figure 7. The interface of the online laboratory work page on chemcollective

OLabs: Innovation in Virtual Laboratories for Science Education

OLabs (http://www.olabs.edu.in/) is a virtual laboratory platform designed by CDAC Mumbai and Amrita University and funded by the Department of Electronics and Information Technology (Deity). This platform offers experiment-based learning experiences that can be accessed individually, allowing students to conduct experiments anytime, anywhere, in a more flexible, economical, and efficient manner. OLabs integrates tutorials, animations, videos, graphics, and simulations, providing detailed information through summaries and catering to the various learning styles of students (Azma et al., 2022; Quraisy et al., 2023).

The main interface of the OLabs website can be seen in Figure 10. The site provides various features, including an "About" section containing Frequently Asked Questions (FAQ) with common questions and answers about OLabs. Moreover, the "In the news" menu contains news related to OLabs, and the platform facilitates workshops through the "Training" menu. Account registration for teachers, students, and educational institutions can be done through the "Registration" menu. OLabs supports language diversity by providing translations of the site into eight languages.

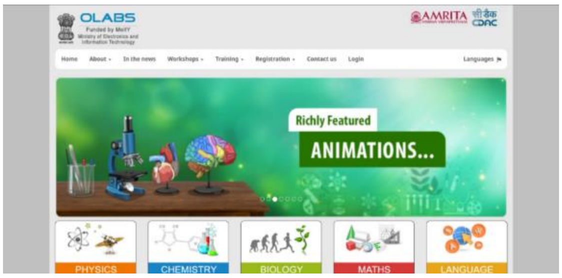

Figure 8. The main interface of the OLabs website

Experiments offered by OLabs cover subjects like physics, chemistry, and biology for grades 9 to 12, as well as English and mathematics for grades 9 and 10. Users can access biology experiment simulations by selecting "biology" from the "Home" menu. Various biology experiments are displayed (Figure 11), and users can choose the desired topic. The experiment view, as shown in Figure 12, provides theoretical information, images of equipment and materials, as well as step-by-step experiment procedures. Animated experiment videos and real lab practical videos are available through the "Animation" and "Video" menus, guiding users in conducting simulations in the "Simulator" menu, as depicted in Figure 13 and Figure 14.

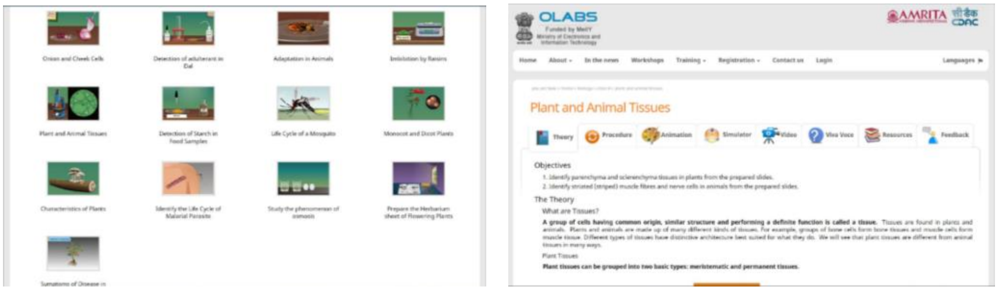

Figure 9. Various biology experiments on the OLabs website and The interface of plant and animal tissues

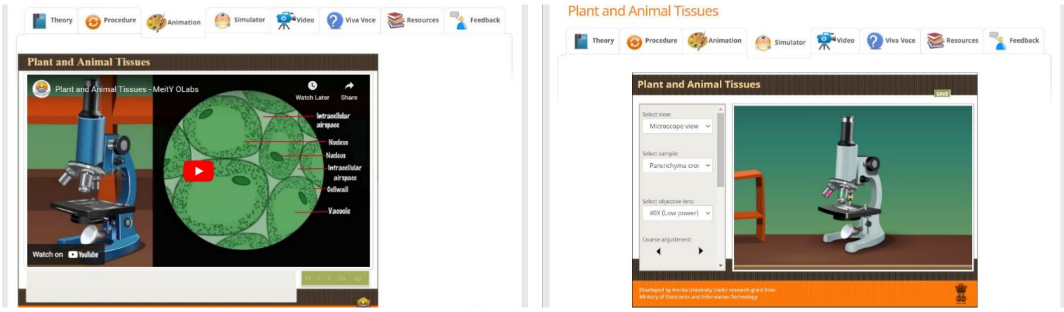

Figure 10. The interface of the online laboratory work page on OLabs and The interface of the online laboratory work page on OLabs

After applying the experiment simulations, OLabs presents the experiment results, such as parenchyma cross-section structure, accompanied by brief explanations as shown in Figure 15. Additionally, there is a "Viva Voce" feature containing practice questions or post-tests to assess students' understanding of the conducted virtual experiments. With its ease of access, rich interactive experiences, and innovative features, OLabs opens the door to engaging, profound, and relevant science learning for students in this digital era.

Figure 11. Display of experimental results

Comparison of Virtual Laboratory Platforms in Science Learning

The virtual laboratory platforms analyzed in this article have their respective advantages and disadvantages in terms of the devices used, implementation, learning materials, and user interfaces. A comparison between the strengths and weaknesses of these platforms is presented in Table 1.

Table 1. Comparison of several virtual laboratory platforms

Aspect	PhET	Chemcollective	OLabs
Device	Flexible	Flexible, but it is recommended to use a laptop.	Flexible
Ease of access	Internet-based or without internet	Internet-based	Internet-based
Operation	Without or with an account	Without an account	Without or with an account
Superior facilities	Learning objectives, material tips	Video tutorials, practice questions	Video tutorials, experimental theory, written work procedures, and assessment sheets
Display	Interesting and colorful	Less interactive	Interesting and colorful

Table 1 provides a comparison of several virtual laboratory platforms that teachers can consider when choosing a suitable platform for science learning. From the table, it can be concluded that all four platforms can be accessed both via laptops and Android devices. However, for Chemcollective, it is recommended to use a laptop, as using Android requires a desktop mode that shrinks the display, resulting in difficulties during simulations.

All platforms can be accessed through the internet, but PhET can also be accessed offline by downloading simulation data beforehand. All these platforms can be used without requiring account creation. However, for PhET and OLabs, creating an account can provide access to additional features. For instance, PhET offers various login options for different users, such as teachers, students, translator researchers, parents, school administrators, curriculum specialists, media/IT specialists, and education product providers. Therefore, activities on PhET can be customized according to the needs of these users. For example, teachers can utilize teaching tips using simulations. On the OLabs platform, teachers and students can organize their activities in a more structured manner.

Although all three platforms have unique displays and features, only PhET provides the Indonesian language option. However, other platforms can use Indonesian with the help of translation features in the browser being used.

Table 2 shows the various types of simulation materials offered by the three virtual laboratory platforms. Each platform presents different simulation materials. Therefore, teachers and students can choose a platform based on the materials they want to study. The use of virtual laboratories in learning the presented materials can enhance students' generic science skills and also improve students' affectivity, making virtual laboratories a good choice. Previous research indicated that the use of virtual laboratories improved students' learning outcomes, metacognitive skills, and concept formation in various subjects (Arda, 2022; Azma et al., 2022; Bogar et al., 2023; Darwis & Hardiansyah, 2021; Dewa et al., 2020; Hapsari et al., 2021; Hastuti, 2021; Hikmah et al., 2017; Lutfi & Hidayah, 2017; Muhali et al., 2021; Riantoni et al., 2019; Sari et al., 2016; Wati, 2021).

Table 2. Types of simulation materials provided by virtual laboratory platforms

Platform	Provided Simulation Materials
PhET	Physics: Motion, Sound & Waves, Work, Energy & Power, Heat & Thermo, Quantum Phenomena, Light & Radiation, Electricity, Magnets & Circuits; Chemistry: General Chemistry, Quantum Chemistry; Math: Math Concepts, Math Applications; Earth Science; Biology
Chemcollective	Stoichiometry, Thermochemistry, Kinetics, Equilibrium, Acid-Base Chemistry, Solubility, Oxidation/Reduction and Electrochemistry, Analytical Chemistry/Lab Techniques, Physical Chemistry, Properties of Solutions
OLabs	Physics, Chemistry, Biology, Maths, Language, Science, Computer, AR/VR, Social Science

Considering this comparison, teachers have a clear guideline for choosing the virtual laboratory platform that best suits their science teaching needs.

CONCLUSION

The results of the literature review indicate that there are several virtual laboratory platforms that can be used in science education. When choosing a platform, teachers need to consider the strengths, weaknesses, and availability of materials provided by each platform, such as PhET, Chemcollective, and Olabs. By understanding the characteristics of each platform, teachers can make informed decisions in selecting the appropriate virtual laboratory platform that aligns with the learning objectives they aim to achieve.

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