# Peeking into the Sophisticated World of Interactive Science Simulations*

Subhadip Senapati
Prayoga Institute of Education Research
Bengaluru 560 116, India
subhadip.senapati@prayoga.org.in

**The growth and popularity of virtual science laboratories have skyrocketed all over the world in recent years due to the covid-19 pandemic. India has also adopted the idea of remote learning, but the overall utilization of virtual science labs to complement remote science learning has been slow and inadequate so far. This article aims to introduce the Indian audience to the world of three relatively new virtual laboratories (Beyond Labz, Labster, and Praxilabs) that can be useful for undergraduate science education. The salient features, experimental demonstration, and merits and demerits of these three platforms have been discussed in this article.**

## 1. Introduction

Science education involves two critical components for teaching and learning – textbook content and practical experiments. Both are critical for creating an ideal science education environment by complementing each other. Online learning has shown significant growth in the last decade and emerged as perhaps the only mode of education during the worldwide lockdown in 2020 due to the covid-19 pandemic. Students were able to continue their education as a result of the development of several online teaching platforms. However, having laboratory facilities at home for each student is impractical and impossible. This is where virtual lab plays a key role and empowers the students to conduct scientific experiments virtually to help them with their understanding of the science subjects. A virtual laboratory is a computer-based interactive simulation that students can use to conduct scientific

**Keywords**
Virtual science labs, online simulation, Beyond Labz, Labster, Praxilabs.

*Vol.27, No.11, DOI: https://doi.org/10.1007/s12045-022-1493-0

experiments using tools or materials, which have no real existence in the physical world [1]. The past few years have seen tremendous growth in the virtual lab domain, and more and more people from academia and industry are becoming inclined to use simulation-based virtual lab experiences. From the era of simple 2D virtual labs, we have now moved to highly sophisticated, more realistic 3D virtual labs with advanced simulation options. There are many reasons behind virtual labs gaining traction in the last decade-

- Online or distant learning started to become popular in the last decade, and for distant learning of science, virtual labs are the ideal substitute for actual labs to complement textbook learning.
- Lack of proper infrastructure or equipment to carry out actual experiments
- The cost of equipment, apparatus, instruments, and materials in actual labs could be very high
- The virtual lab environment is safe and free from potential laboratory hazards
- Experiments can be repeated by the students as many times as they wish
- With the advancement of technology, graphics have improved significantly. 3D animations and simulations in virtual labs have become more realistic, making them much more attractive.

There are many types of virtual labs developed by different academic groups, institutions, and companies. Depending on the specifications, it can either be online or offline and 2D or 3D. Some extremely informative videos with detailed instructions on lab activities can be accessed via YouTube or scientific blogs. Moreover, peer-reviewed journal like the *Journal of Visualized*

*Experiments* (JoVE) publishes manuscripts with experimental methods in video formats. All of these platforms have different pros and cons. PhET, the brainchild of Nobel laureate Dr. Carl Wieman, is a pioneer in the world of virtual labs and remains popular to date. But PhET contains simulations mainly aimed at primary and secondary school students [2]. In this article, we will focus on other relatively new virtual labs, which are suitable for senior secondary and undergraduate students, and address their suitability for science education.

## 2. Virtual Labs

### 2.1 Beyond Labz

Beyond Labz (earlier known as Y Science Laboratories) is one of the most sophisticated virtual labs available right now. Beyond Labz was created at Brigham Young University (BYU, located in Utah, USA) and contains simulations from physics, chemistry, and biology (offered as general chemistry, organic chemistry, biology, physics, and physical science) (*Figure* 1) [3]. In these laboratories, students go through a simulated virtual environment where they make the choices and decisions that they would normally make inside an actual laboratory and experience the resulting consequences (yes, things can even explode in simulation from Beyond Labz, albeit virtually!). Students can perform experiments on a wide range of topics such as mechanics, optics, circuits, calorimetry, quantum (physics), microscopy, genetics, molecular biology, ecology, systematics (biology), titration, inorganic analysis, organic synthesis and functional group, gas laws (chemistry).

Beyond Labz offers a separate section for organic chemistry with an amazing selection of simulations. Simulations based on detailed organic synthesis are currently offered only by Beyond Labz among all the virtual labs mentioned in this article. As part of the demonstration process, a detailed synthetic process of 3-methylbutyl phenylacetate, an organic ester has been described here. First, the correct starting materials 3-methyl-1-butanol and 2-phenylacetic

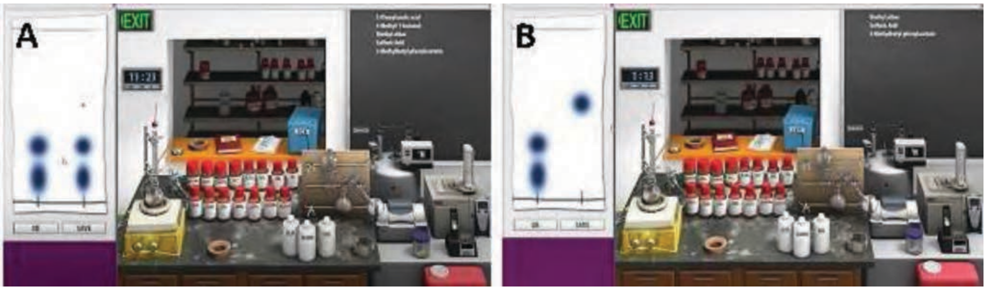

**Figure 1.** **(A)** Typical bench space for organic synthesis offered by Beyond Labz. Thin-layer chromatography (TLC) shows the presence of both the starting materials. The compounds present in the reaction mixture at any point in time are displayed on the board. **(B)** Completion of the reaction can be monitored by TLC. Pure compounds can be isolated by solvent extraction and then by using rota-vapor. Finally, the product can be characterized using NMR, FT-IR, and mass spectrometry.

acid, diethyl ether solvent, and sulfuric acid catalyst need to be transferred to the round bottom flask. Structures of the compounds being used in the synthesis are displayed on the board behind the lab bench. The reaction set-up then needs to be completed by transferring the round bottom flask on top of a hotplate, followed by adding a glass condenser and maintaining the reaction mixture under nitrogen gas. Once the reaction is started, the progress can be monitored using thin-layer chromatography (TLC). After the reaction is over, the product can be separated and purified using a separating funnel and rotary evaporator (auto-simulated). Finally, the product can be characterized by NMR ($^1$H, $^{13}$C), mass spectrometry, and FT-IR and can be verified by comparing the spectra with the reference spectra for those compounds from the 'notebook' (literature data). Detailed analysis of organic and inorganic simulations offered by Beyond Labz can be found in the literature [4,5].

Beyond Labz provides remarkable flexibility for conducting online experiments. Students can either select the general virtual labs (for example, synthesis and qualitative analysis in organic chemistry) and perform the experiments from the scratch or they can opt for the preset experiments (alkene reaction, diene reaction, oxidation-reduction, aromatic substitution, etc.), where the lab bench is already pre-populated with the required chemicals and equipment for a particular experiment. Some simulations (such as quantum, kinematics, and organic synthesis) are really cutting-edge, detail-oriented, and exclusively offered by Beyond Labz. All the virtual labs include detailed laboratory activities and notebooks for students to record procedures and data, and submit their final results. Instructors can develop and use their own lab activities too. Beyond Labz covers some fundamental concepts to advanced-level topics and caters to both senior secondary and undergraduate students. Unfortunately, all these fantastic features come at a cost – users need to purchase an individual license or obtain one through the institution. Also, some of the labs can be quite complex, challenging, and time-consuming for first-time users.

## 2.2 Labster

Labster was launched in 2011 as a biotech education startup, and perhaps offers one of the most immersive virtual-lab experiences among the commercially available ones. Built on advanced algorithms and cutting-edge technologies, Labster provides a visually appealing 3D environment for the students, who explore different science concepts through story-telling or games. The attractive layout naturally appeals to young students, as they navigate through different topics from biology, chemistry, physics, medicine, and engineering and can experience and learn from any of the 216 simulations being offered currently (*Figure* 2) [6]. Additionally, it can train students through an interactive simulation on lab safety and guides the students about the dos and don'ts inside a lab environment. Labster also offers quite a few advanced-level concepts, just like Beyond Labz, and is suitable for students from high schools and universities. Arguably, Labster offers the most diverse simulations across the science subjects among all the commercially available virtual labs and has recently started to expand its collections by including a few simulations from the engineering and medicine field as well. Labster covers a wide variety of topics in physics (such as electricity, mechanics, electromagnetism, optics, and energy). For biology, Labster offers plenty of simulations that cover domains like fundamental biology, biochemistry, physiology, ecology, evolution, food science, nutrition, cellular and molecular biology, biotechnology, and genetics. Students can conduct online experiments on basic biol-

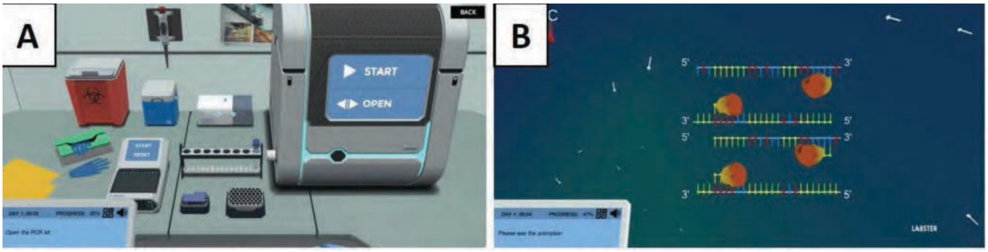


**Figure 2.** **(A)** Typical set-up for PCR experiment offered by Labster. PCR kit, PCR machine, gel electrophoresis system, and basic lab equipment (safety goggles, lab coat, gloves, pipette, bin, etc.) are provided. For all the simulations, LabPad is provided (bottom-left corner), which guides the students through the simulation. **(B)** Educational animation on PCR technologies played during the simulation followed by a practice quiz.

ogy concepts like cell division, respiration, enzyme kinetics, and gel electrophoresis to advanced and more complex ones like basic genetics, gene regulation, gene therapy, CRISPR, molecular cloning, or next-generation sequencing. Labster furnishes simulations for a wide range of basic and advanced chemistry concepts (matter, acid-base, atomic structure, chemical bonding, titration, fundamentals of organic chemistry, types of organic reactions, and nuclear chemistry to name a few). Students can also perform virtual simulations on various separation techniques such as liquid-liquid extraction, distillation, and recrystallization.

As part of the demonstration process and evaluation of its efficacy, simulation on polymerase chain reaction (PCR) has been chosen for this article. It is designed in an interesting way to catch students' interest. Students are asked to solve a murder mystery by exploring PCR and gel electrophoresis. First, students are required to mix the correct reagents using a PCR kit and run the PCR experiment on the DNA collected from the crime scene. At this point, a 3D animated video describing the PCR techniques at the molecular level is played, explaining DNA structure and the process of replication, followed by a practice quiz. Students then load all the DNA samples (collected from the murder scene and three suspects) and run a gel. The theory behind gel electrophoresis is explained through another animated video at this point. Eventually, students identify the suspect by comparing the gel pattern. There is a separate 'Theory' section, where students can learn the basic and lab-specific theory behind PCR, and a 'Quiz' section at the end to test their understanding. The format and specifications are similar to other simulations as well. Labster has already been extremely popular within the scientific community worldwide and quite a few studies have been conducted using Labster as an experimental platform. [7,8]

Labster is one of the most widely used virtual lab platforms due to its sheer number of simulations across different subjects, attractive presentation, and availability of app versions. Labster is equipped with 'faculty training' and 'automated grading' options and the simulations are accompanied by detailed protocols, underlying theories, and quizzes and allow the students to proceed at their own pace. To keep students hooked to the virtual labs and fuel their inquisitive nature, often simulations are designed using a game-like or story-telling format – such as investigating a mysterious plant disease in 'confocal microscopy', identifying a deep-sea creature in 'evolution', or learning about 'light and polarization' by capturing the beautiful wildlife in Antarctica and explained by one of the greatest physicists of all time, professor Albert Einstein. Unfortunately, the web-version Labster is also behind a pay-to-use platform, and users need to obtain a license (individually or through institutions) before using it. It also needs a constant internet connection, and users have sometimes faced issues regarding system configuration, slow progress, or being completely stuck inside a simulation. In early 2021, Labster launched its app version in India, which is free to use and has the potential to change the virtual lab landscape in the country.

### 2.3 PraxiLabs

PraxiLabs is another sophisticated virtual lab with 3D simulations offered in physics, chemistry, and biology. It offers immersive simulations similar to Labster, and currently contains 91 simulations in its database (physics 23, chemistry 43, biology 25) (*Figure* 3) [9]. Physics virtual lab includes concepts like heat and thermodynamics, electricity, magnetism, electronics, waves, modern physics, and mechanics. Each concept comprises two or more physics simulations, where students can perform virtual experiments using virtual tools. For example, under 'waves', students can verify Hooke's Law, or measure the speed of sound

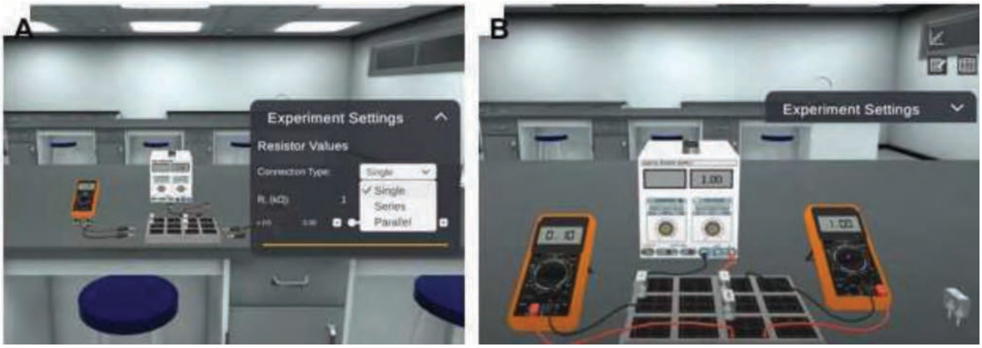


**Figure 3.** **(A)** Pre-populated lab bench to verify Ohm's law using Praxilabs. Students can opt for different connection types (single, series, and parallel) at the beginning of the experiment and choose the resistance value(s). **(B)** 'Zoomed-in' view of the experimental set-up. Students are provided with a power supply box, resistance box, and two multimeters. Students can measure the current using the ammeter and check the validity of Ohm's law based on other information.

using open and closed columns, and under 'modern physics', students can work on black-body radiation, Millikan oil-drop experiment, Michelson's interferometer, or I-V characteristics of the solar cell. The biology virtual lab includes some exciting simulations in the domains of basic biochemistry, molecular biology, immunology, and toxicology. Some of these simulations are extraction of DNA and RNA, cDNA synthesis, conventional PCR and Real-Time PCR, gel electrophoresis, western blot, DNA sequencing (molecular biology), enzyme-linked immunosorbent assay (ELISA), flow cytometry (immunology), or different cell viability assays (toxicology). Chemistry virtual labs cover a series of simulations, which are inorganic, organic, and analytical in nature. Organic and inorganic virtual labs mostly contain simulations based on tests for a particular functional group (amide, carboxylic, hydroxyl, etc.) or radical (sulfate, carbonate, zinc, aluminium, etc.), whereas, analytical virtual lab comprises concentration determination through titration, standardization, gravimetric analysis.

For instructional purposes and guidance, *Figure* 3 describes a step-by-step simulation to verify Ohm's law and measure resistance. In this simulation, students can measure the current by trying out different combinations and magnitudes of resistances (single, series, and parallel). Students are provided with a power supply box, resistance box, and two multimeters (functioning as an ammeter and a voltmeter, respectively). Students first need to connect all the instruments/equipment so that a continuous circuit is formed. Then they can check the validity of Ohm's law by measuring the current after altering the voltage supply, resistance magnitude, and combination types. If students are stuck at a particular point during the experiment, they can refer to the written instructions and animated video to figure out the next step. These features are available for all the simulations and can act as guiding tools throughout any experiment.

Praxilabs has a wonderful collection of physics and biology virtual labs, where students can carry out several advanced simulations. Some of these simulations are exclusively offered by only Praxilabs and are not available for other virtual labs mentioned here (such as cell viability assay (toxicology), cDNA synthesis, Polarographic Oxygen Respirometry (Bioenergetics), determination of Young's modulus). Students can access all the simulations through a computer, tablet, or even a smartphone – but only through the browser, as the app version is not available yet. All virtual labs are supported by detailed protocol (pdf) and animated videos to assist students with each step of the experiment. It also comes with practice exercises and quizzes to complement the learning process. However, PraxiLabs has a somewhat limited collection for chemistry simulations and primarily offers only tests for inorganic radicals and organic functional groups, and some analytical chemistry-based experiments. Some fundamental yet important chemistry concepts are missing – for instance, atomic structure, acid-base, and organic synthesis to name a few. Overall, it is another virtual lab that has the potential to engage the students in a realistic environment and offers 6 free simulations (2 each for physics, chemistry, and biology). But users need to pay to access the rest of the simulations and choose from three different subscription models.

**Box 1. Key Features for all Three Virtual Labs Discussed in this Article:**

**1. Beyond Labz**

**Subjects:** general chemistry, organic chemistry, biology, physics, and physical science
**Target audience:** senior secondary, undergraduate
**Platform:** website
**Connectivity:** online, offline
**Access:** free trial for limited time, then paid access

**2. Labster**

**Subjects:** physics, chemistry, biology, medicine, engineering
**Target audience:** senior secondary, undergraduate
**Platform:** website, app (beta version available only in selected countries)
**Connectivity:** online
**Access:** free trial through institutions, free lab safety simulation; then paid access. Recently launched app version is free in India.

**3. Praxilabs**

**Subjects:** physics, chemistry, biology
**Target audience:** senior secondary, undergraduate
**Platform:** website
**Connectivity:** online
**Access:** 6 free simulations, rest behind a paywall

## 3. Future scopes and the initiatives taken by Government of India

In recent years, the virtual lab industry has been booming exponentially and a wide number of virtual labs have been developed across subjects/disciplines and levels. In this article, only three state-of-the-art virtual labs have been described, mostly suited for scientific experiments at the secondary and undergraduate levels. But there are plenty more that cater to the different needs of the students and teachers from the scientific background. Even though some European countries and the United States had already warmed up to the idea of virtual laboratories in the early part of the twenty-first century and realized its importance even more during the worldwide pandemic, India was a little too slow to adopt the idea at the beginning despite the initiatives taken by the Government of India almost a decade back. But during the lockdown periods in 2020 and 2021, it became obvious how important a role virtual labs can play for science learning and its popularity started to soar worldwide. India was no different and during the lockdown periods, the virtual lab gained a lot of new users from India as well. It must be noted that virtual labs might have been the only mode for conducting experiments when the academic institutions were closed, it is highly unlikely that they would replace the traditional physical labs when the world opens up. Rather virtual labs can perfectly complement the physical experiments as students can get accustomed to the experimental techniques through online simulations even before the physical lab experience or refresh their memories and analyze their observations through online simulation after the physical labs. Hence, the blending of virtual and physical labs can become a key educational pedagogy in the future.

The Ministry of Electronics and Information Technology and the Ministry of Education (Government of India) provided funding for two different virtual labs aimed at two different levels of students – OLabs (online labs) and VLab (virtual labs), respectively [10,11]. OLabs, developed by Amrita CREATE (Center for Research in Advanced Technologies for Education at Amrita Vishwa Vidyapeetham) in collaboration with CDAC (Centre for Development for Advanced Computing), primarily provides online simulations for classes 9-12, based on NCERT/CBSE and the State Board Syllabus. At present, OLabs offers simulations in physics, chemistry, biology, and mathematics and has 4,41,412 registered users. It has also trained 27,748 teachers from 8,080 schools. On the other hand, VLab has been developed with advanced-level students in mind and some of the premium institutes in India, including the IITs (Indian Institute of Technology) have participated in the development process. At present, VLab offers simulations in various disciplines of Science and Engineering. Both OLabs and VLab provide theoretical background, detailed procedure, instructional videos (real-life and/or animated), and self-assessment options to supplement the actual simulations and these features are extremely helpful to the users.

## 4. Summary

The covid-19 pandemic and subsequent lockdown in 2020 resulted in the shift of classroom teaching towards online teaching, and students continued to learn from the comfort of their homes. But hands-on experiments are integral parts of teaching science, and that was not possible anymore due to a lack of access to actual laboratories. Virtual labs came to the rescue and the interactive lab-like simulations available online complemented online learning effectively. Also, as mentioned before, virtual labs can provide lab-like experiences at a much lower cost, without any proper infrastructure, apparatus, equipment, and instruments [12]. Due to their convenient, safe, cost-effective, and intuitive nature, virtual labs have the potential to be a key part of the future of online education, especially in developing countries, including India. India's new National Education Policy (NEP 2020) has emphasized online learning and experiential learning to a significant extent and virtual labs can play a critical role in both these cases [13]. In this article, the main features of three different virtual labs have been discussed (summarized in Box 1), followed by a demonstration of simulations from each platform, and a discussion about their merits and demerits. Of course, it is difficult for a single instructional technique to be a perfect fit for teaching and learning; and the virtual lab is no different. One may need to be tech-savvy (especially for the high-end virtual labs) and have access to decent system configuration and a stable internet connection. Also, accessing these virtual labs may be expensive for the students and the educational institutes may have to subscribe for access. Most importantly, even if virtual labs have the potential to be an important tool to learn science in the coming years, it must be kept in mind that it is never going to be a like-for-like replacement for the actual lab experience. Rather, virtual labs are perhaps best suited to complement the techniques learned in a physical lab and can help the students prosper through a blended learning pedagogy.

## Suggested Reading


[1] **C E Wieman and K K Perkins, A powerful tool for teaching science, *Nature Physics*, 2, pp.290–292, 2006.**

[2] **S Senapati, Virtual labs, real science, *Science in School*, 52, 2021.**

[3] **S Marincean and S L Scribner, Remote Organic Chemistry Laboratories at University of Michigan—Dearborn, *J. Chem. Educ*., Vol.97, No.9, pp.3074–3078, 2020.**

[4] **B F Woodfield, H R Catlin, G L Waddoups, M S Moore, R Swan, R Allen and G Bodily, The Virtual ChemLab Project: A Realistic and Sophisticated Simulation of Inorganic Qualitative Analysis, *J. Chem. Educ*., Vol.81, No.11, pp.1672–1678, 2004.**

[5] **B F Woodfield, M B Andrus, T Andersen, J Miller, B Simmons, R Stanger, G L Waddoups, M S Moore, R Swan, R Allen and G Bodily, The Virtual ChemLab Project: A Realisticand Sophisticated Simulation of Organic Synthesis and Organic Qualitative Analysis, *J. Chem. Educ*., Vol.82, No.11, pp.1728–1735, 2005.**

[6] **L E de Vries and M May, Virtual laboratory simulation in the education of laboratory technicians–motivation and study intensity, *Biochem. Mol. Biol. Educ*., Vol.47, No.3, pp.257–262, 2019.**

[7] **S C de la Heras, B Kensington-Miller, B Young, V Gonzalez, U Kruhne, S S Mansouri, S Baroutian, Benefits and Challenges of a Virtual Laboratory in Chemical and Biochemical Engineering: Students' Experiences in Fermentation, *J. Chem. Educ*., Vol.98, No.3, pp.866–875, 2021.**

[8] **K S Alvarez, Using Virtual Simulations in Online Laboratory Instruction and Active Learning Exercises as a Response to Instructional Challenges during COVID-19, *J. Microbiol. Biol. Educ*., Vol.22, No.1, pp.1–4, 2021.**

[9] **Praxilabs, https://praxilabs.com/**

[10] **http://www.olabs.edu.in/ and https://www.vlab.co.in/**

[11] **P Nedungadi, P Malini and R Raman, Inquiry Based Learning Pedagogy for Chemistry Practical Experiments Using OLabs, *Advances in Intelligent Informatics* (Springer), pp.633–642, 2021.**

[12] **N Ali and S Ullah, Review to Analyze and Compare Virtual Chemistry Laboratories for Their Use in Education, *J. Chem. Educ*., Vol.97, No.10, pp.3563–3574, 2020.**

[13] **S Senapati, H S Nagaraja and T N Guru Row. Chemical Education and Research in India: Challenges, Perspectives, and Future Opportunities in Line with the National Education Policy 2020 *J. Chem. Educ*. 2022. https://doi.org/10.1021/acs.jchemed.2c00454.**