

ORIGINAL RESEARCH ARTICLE

Design and implementation of an interactive virtual laboratory in distance education in Argentine universities

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ABSTRACT

The adoption of distance education (DE) in Argentine universities has long been in practice and was accelerated by the COVID-19 pandemic. The effectiveness of online learning (OL) in such situations has contributed a lot, but it has limitations, especially in delivering practical laboratory-based education. Interactive virtual laboratories (IVLs) are being designed within the framework of this attempt in order to address these types of issues. The purpose of these virtual laboratories is to provide learners who have recently graduated from DE courses in science and engineering with the potential to get hands-on training. The layout and creation of an IVL application that attempts to recreate face-to-face laboratory experiences within an online environment is the subject of examination among the researchers of the current research. This method of HE focuses on integrating college-level teaching with real-world use to provide learners with a complete education subject to their physiological limitations. The program's goal is to address immediate challenges and provide an architecture for Argentina's higher education (AHE) system's constant evolution.

Keywords: distance education; interactive virtual laboratories; online learning; cloud computing

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1. Introduction

For the benefit of its enormous number of learners, Argentina's universities have historically employed different approaches to teaching. The conventional higher education (HE) system consists of classroom teaching and laboratory experiences for students, which require hands-on testing and personal machine use^[1]. Technological innovation and evolving social needs have made distance education (DE) increasingly common, enabling accessibility and versatility to HE^[2].

The global COVID-19 epidemic provided a more applicant spark that helped promote the spread of DE^[3]. The global HE institutions, such as Argentina, stopped their on-campus teaching to prevent the disease from propagating, providing online learning (OL) educational institutions as the only means for ongoing learning. During this time, DE's mobility, the effectiveness of costs, and autonomy in learning became evident^[4]. The use of this technique permitted students to continue learning during lockdowns and solitary confinement, which had been essential for academic endeavors.

In practical subjects, the DE has unique challenges. Classes developed in laboratories have become vital to scientific and engineering programs, which lag in DE. Practical training labs are

challenging to find OL, which may compromise practical ideas^[5]. The absence of close attention and physical connection with laboratory tools could interfere with essential skills and personal experience obtained via hands-on training.

All DE-mode colleges and universities are exploring multiple possibilities, such as the interactive virtual laboratory (IVL), to address similar challenging circumstances. IVLs bridge theory with practice^[6]. They permit learners to practice tests, get involved with scientific methods, and analyze data without taking advantage of real laboratory settings. The use of this method minimizes DE's limitations and enhances HE by providing an environment that is controlled^[7-10]. This attempt promises to address DE laboratory class problems for Argentine Higher Education (AHE). IVLs are incorporated into the learning program to provide DE students with laboratory training and avoid remote locations or physical obstacles to their learning^[11-15]. This research developed and tested an IVL for DE-focused AHE institutions. The research project provided a structure for developing and conducted the IVL platform known as "interactive virtual laboratories (IVL)" via deep specification evaluation, planning, and execution that was user-friendly and fit with the HE objectives. The plan of attack had been implemented with assistance from sample HE institutions, drew students, and derived 90% acceptance from the same premises.

The paper is organized as follows: section 2 presents the methodology, section 3 presents the evaluation of the model, and section 4 concludes the work.

2. Virtual laboratories: An overview

VL is an innovative DE technique that models lab environments with digital tools. These systems allow students to analyze data and experiment using simulations, active modules, and augmented reality (AR) and virtual reality (VR)^[16-20]. VLS provide researchers practical, hands-on, readily available, and secure knowledge that is more appropriate and required in scenarios where conventional lab tools are limited, or tests are too unsafe or cost-prohibitive to be performed in real life.

2.1. Virtual laboratories in distance learning

VL has transformed DE education, particularly when OL and adaptable learning (AL) is required. VLS hyperlink academic knowledge and real-time applications, allowing distant learners to obtain significant hands-on training without laboratory equipment^[21-25]. Their lively atmosphere for learning may be adapted for various OL methods and steps. DE VLS present periodic assessments and opinions, allowing teachers to monitor student achievement and adapt instruction to differing HE requirements.

2.2. Types of virtual laboratories

- (1) Simulation-based laboratories: They employ computer models to simulate real-world scenarios, allowing students to conduct experiments and observe outcomes virtually.
- (2) Remote laboratories: These labs provide remote access and control to real lab equipment located at different locations via online. Students can conduct experiments by operating the equipment remotely.
- (3) Mixed-reality laboratories: Combines virtual and real environments. Mixed-reality labs use technologies like AR and VR to create immersive learning experiences.
- (4) Web-based laboratories: These are accessible through a web browser without specialized software or hardware.
- (5) Gamified laboratories: These labs use gamification elements, such as points, levels, and rewards, to make the learning process more engaging and interactive.

3. Development model for the IVL model

The development of the proposed IVL model has followed the following life cycle model, as shown in

Figure 1, starting with requirement analysis, then defining and designing, coding and testing, and finally, deployment and maintenance. Each of the steps carried out in the development of IVL is discussed in the following sections.

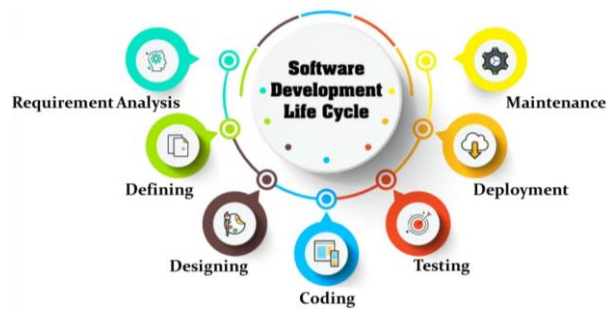


Figure 1. SDLC model.

3.1. Requirement analysis for the IVL

The requirement analysis phase was the first step in developing the IVL model, which engages in thoroughly understanding the HE needs and determining the technical and user requirements. The following criteria are considered in this phase.

i) Identifying HE needs:

- Collaboration with educators and students: To align IVL with the stated HE objectives, this step engaged in extensive consultations with educators, academic stakeholders, and industry experts, and their requirements were recorded. These discussions aimed to understand the pedagogical goals, curricular requirements, and learning outcomes expected from the VL^[26–30].
- Understanding the target audience: The target audience is students and educators, and their needs were analyzed to grasp their academic backgrounds, technological proficiency, and learning styles.
- Identifying specific requirements for the virtual lab: Specific requirements include the type of experiments, level of complexity, and fields of study that were placed.

ii) Determining technical and user requirements:

- Technical specifications: The technical requirement identifies the hardware and software needs. This involves assessing the computational power required for testing simulations and the need for any specialized equipment like VR headsets or additional peripherals^[31–35].
- Software needs: The software requirements included the selection of appropriate programming languages, including the simulation software and other tools necessary for creating interactive and engaging content.
- User requirements—Accessibility and usability: This involved designing an intuitive user interface that provides support for screen readers and ensuring the content is available in multiple formats.

3.2. Design of the VL applications

The design phase of the IVL model capitalized on insights learned from the requirement analysis. This phase presents a design layout for the IVL that is tailored to cater to three types of users: students, laboratory instructors, and system administrators^[36–40]. The following outlines the design elements based on the provided learning scenario:

(i) User registration and authentication: Students can register for the application by choosing one of nine disciplines: Electronics and communications, computer science and engineering, electrical engineering, mechanical engineering, chemical engineering, biotechnology and biomedical engineering, civil engineering, physical sciences, and chemical sciences. After successful registration, the students receive a unique username and password.

(ii) Login and session management: Students log in to the application using their credentials. A successful

login generates a session ID, which serves as a unique identifier for each learning session. The session ID tracks the user’s activity and remains active until the user logs out.

(iii) Discipline-specific navigation: The students are directed to their chosen discipline after logging in. Here, the application is presented with a list of available laboratories under that discipline.

(iv) Experiment selection and execution: Students can select an experiment from the list provided under their discipline. Upon selection, the chosen experiment can be directly conducted within the application, with results displayed in the same window.

(v) Interactive learning and communication: During the experiment, the students can engage with peers and instructors. They can discuss the experiment, ask questions, or share insights via a text-based forum.

(vi) Session completion and logout: Upon completing a learning session, the students can log out of the application. Logging out resets the session ID for data security and privacy.

(vii) Feedback mechanism: Each laboratory is accompanied by a feedback questionnaire. This feature allows students to provide valuable feedback on their laboratory experience, which can be used to improve the VL continuously.

3.3. Components

The components for the VL designed as a web-based application were chosen and adopted with a focus on server and client-side specifications with tools and components needed to build an effective system^[41–45].

3.3.1. Server-side specification

(i) Application server and DBMS: Apache tomcat was used as the application server, and data was managed using MySQL (**Table 1**).

(ii) Security and data protection: SSL/TLS encryption was implemented for secure data transmission with OAuth protocols, and data backups were automated using cron jobs.

(iii) API development and integration: RESTful APIs were developed using Node.js with Express.js to communicate between server and client.

Table 1. Server-side specifications.

Server-side component	Specification details
Application server ^[46]	Apache tomcat was chosen for handling multiple concurrent requests efficiently and providing stable performance.
Database management ^[47]	MySQL—selected for scalability and reliable handling of large volumes of data, including user information, experiment details, and session records.
Security and data protection ^[48]	Implement SSL/TLS encryption for secure data transmission, OAuth protocols for user authentication, and regular data backups using cron jobs for data integrity.
API development and integration ^[49]	RESTful APIs developed using Node.js with Express.js to facilitate efficient communication between the server and client sides.

3.3.2. Client-side specification

(i) User interface and experience: The front end was built with HTML5, CSS3, and JavaScript, utilizing React.js. Complex graphics and simulations were rendered using WebGL (**Table 2**).

(ii) Compatibility and performance: Compatible for Google Chrome and Mozilla Firefox. The assets were minified using Webpack.

(iii) Accessibility and inclusivity: The application design followed Web Content Accessibility Guidelines (WCAG) and ARIA labels and roles to enhance screen reader compatibility^[50].

Table 2. Client-side specifications.

Client-side component	Specification details
User interface	It is developed using HTML5, CSS3, and JavaScript with React.js to create a responsive and interactive user interface.
Graphic and simulation rendering	Utilization of WebGL supported by the Three.js library for rendering complex graphics and simulations.
Compatibility and performance	Optimized for Google Chrome and Firefox and with asset minification using Webpack.
Accessibility	The design adheres to Web Content Accessibility Guidelines (WCAG) with ARIA labels for screen reader compatibility, ensuring inclusivity and usability across various devices.

3.4. Implementation

The programming and development of the VL, including the integration of simulations and educational content, were done using the input and feedback from Argentine universities. They provided data regarding the types of simulations and curriculum content for their students. They also assisted in identifying the key features and tools that would best support the learning of their multiple programs^[51–55]. The IVL was hosted with the consideration of high accessibility for all users across these universities. The cloud-based server infrastructure was chosen for its scalability. Continuous testing and refinement of the IVL were done with the input of students and faculty from these universities. Performance testing was conducted in scenarios that simulated actual usage conditions in these universities to ensure the platform’s stability and reliability under real-world conditions^[56–60]. For a smooth transition to the IVL environment, the training sessions were organized for faculty and Information Technology staff to familiarize them with the platform’s capabilities and administration.

3.5. Verification

The proposed laboratory model was hosted in collaboration with three universities from Argentina and offered laboratory courses under nine disciplines, and the VL was hosted under the name “virtual laboratories” using the “URL: https://olab.org.ar”. In this section, a few of the webpages from the site are presented and discussed in **Figure 2**.

(i) Login page: The website features a login interface (**Figure 2**) that prompts for a username, where the user can either enter an email or mobile number followed by a password. Options for new user registration and password recovery are provided. Based on the input user ID, the application takes the user to the corresponding pages.

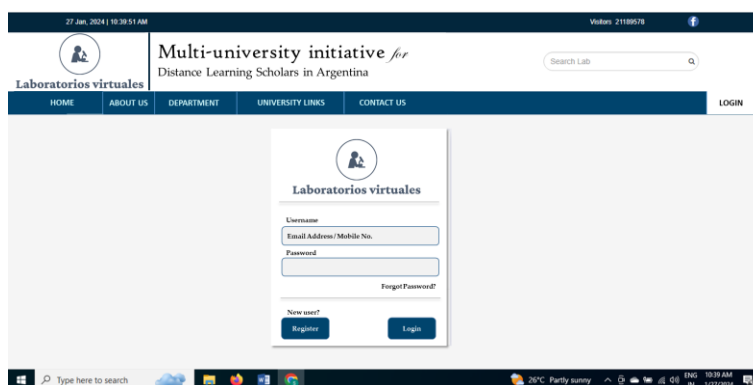


Figure 2. Login page.

(ii) Home page: The home screen (**Figure 3**) shown here depicts the window for a computer science department student. The page provides details of different labs. The student can launch the respective selection of lab. The page also provides navigation to other department and university links. Upon establishing a

selection of lab, the site directs the user to the specific lab page.

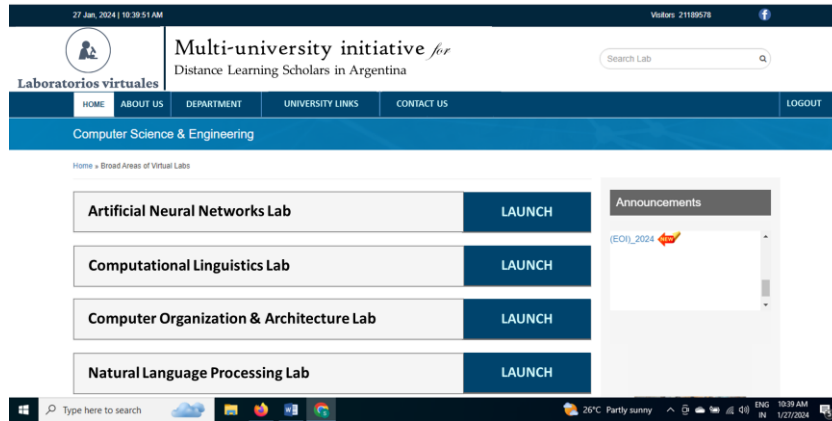


Figure 3. Home page.

(iii) Laboratory page: The pages of the lab page corresponding to “Python programming lab”. The page provides information about the objective of the course, a list of experiments in the lab, the target audience, and feedback on the course. The list of experiments link directs to the respective experiment page (Figure 4).

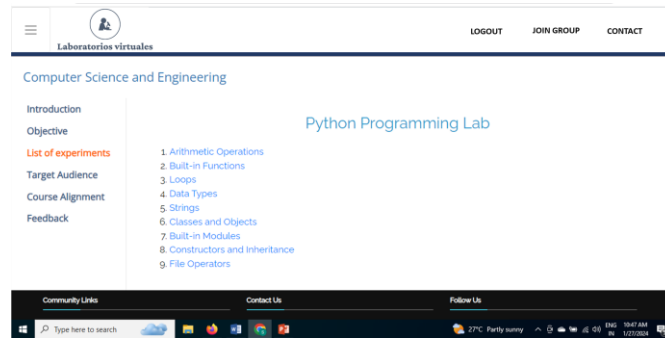


Figure 4. Laboratory page.

(iv) Experiment page: The experiment page (Figure 5) provides the theoretical details of the experiment, post and pretest, and presents the technical know-how of how to experiment. The students can learn through the supplied manuals and experiment with their exposure through the simulation link.

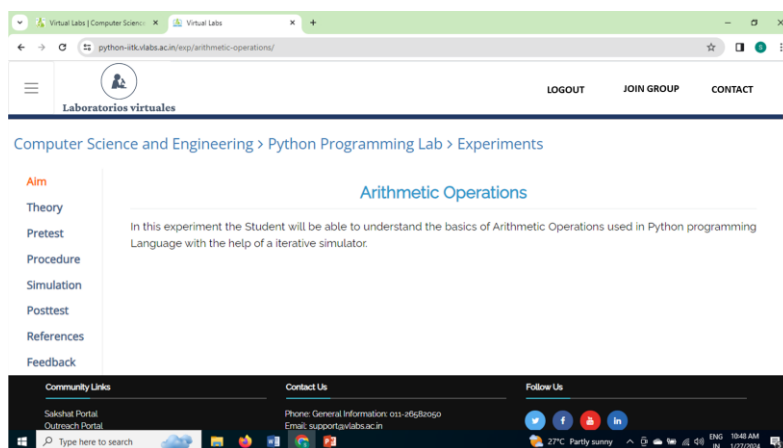


Figure 5. Experiment page.

(v) Simulation page: Figure 6a–c shows the simulation page corresponding to the arithmetic operators experiment in the Python programming lab. The platform provides a simulation environment for the users to have hands-on training about each experiment by providing different input combinations. Also, the students

can get online support by joining the respective groups, posting their queries, and participating in the discussions.

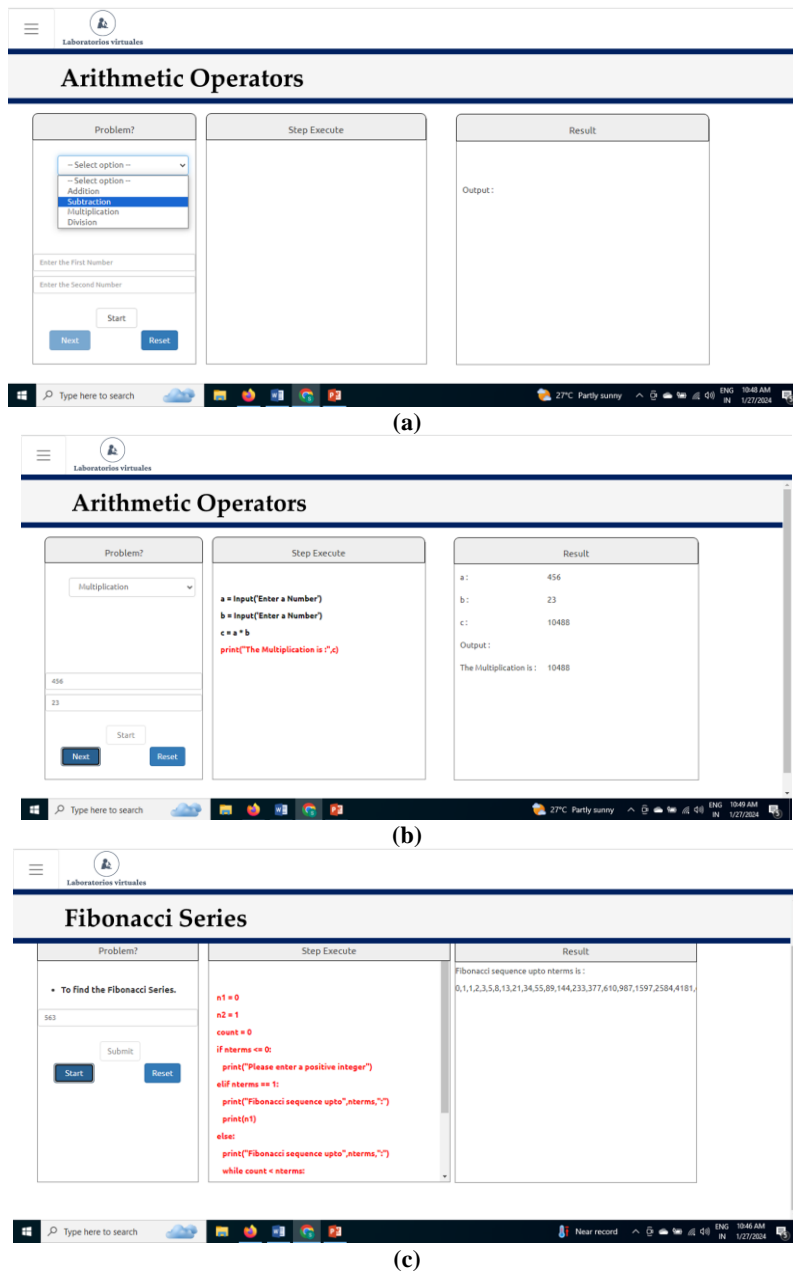


Figure 6. (a)–(c) simulation page.

(vi) Feedback page: **Figure 7** shows the feedback page for the respective lab course; the feedback form contains closed and open-ended questions to measure the experience and understanding of the individual course in terms of simulation environment, manual quality, result experience, understandability of the procedures, content organization and ease of use.

Feedback Page

Laboratorios virtuales

Your name

Click for Date

Select Name of the Institute

Optional! (Institute name is missing in the list)

Your email address

Faculty Student

Select Name of the discipline

Please select one of the options

No. of experiments performed

Questionnaire:

Please help us improve our services by taking a few minutes and answering a few questions about your hands-on experience today.

(a) Feel of simulated labs over actual lab environment simulated.
 Excellent Good Fair Poor

(b) Manual provided was helpful.
 Excellent Good Fair Poor

(c) Getting results after every experiment.
 Excellent Good Fair Poor

(d) Simulation meets the expectations.
 Yes No

(e) Procedure was clear and understandable.
 Yes No

(f) Content was well organized.
 Yes No

(g) Accuracy of the results was consistent.
 Yes No

(h) Ease of performing experiments via Virtual Labs over real lab.
 Yes No

(i) Experiment was relevant to your need.

Figure 7. Feedback page.

3.6. Testing

In assessing the “virtual lab” platform, the application was tested utilizing the black box methodology. This evaluates the application’s functionality without knowing the internal workings to identify operational discrepancies. During the testing phase, an alpha test was conducted to ascertain the application’s performance across different mobile platforms. Each function and submodule were scrutinized. To gather empirical data testing using a sample group of 50 students who participated in a trial run of the VL application. The feedback was largely positive, with approximately 90% of the students rating the application as user-friendly and satisfactory. A summary **Table 3**, included here, consolidates the input, highlighting the application’s ease of use.

Table 3. Summary of the student response.

Questions	Agree (%)	Disagree (%)
The simulated labs reflect a real lab environment effectively.	87	13
The manuals provided are helpful and guide the experiments.	82	18
Results are delivered promptly and clearly after experiments.	90	10
The simulations meet the expected standards of quality.	85	15
The procedures for experiments are clear and understandable.	88	12
The content in the VL is well-organized.	80	20
The results obtained from the lab are consistent.	75	25
Performing experiments is easy compared to a real lab.	78	22
The experiments are relevant to educational or research needs.	92	8

4. Conclusion

This study demonstrated the design and implementation of interactive virtual laboratories (IVLs) in

Argentine universities that showcased a significant stride in the field of online learning (OL). The IVL addresses the gap in providing practical, hands-on laboratory experiences in an OL environment. The IVL was developed by considering severe prerequisite analysis, which covered all the educational needs and technical specifications. The IVL has a user-friendly design with discipline-specific navigation and interactive learning modules. The application was designed with input from three Argentina's higher education (AHE) and covered nine disciplines of science and engineering. The application design, implementation, and verification phases are discussed in detail, and the verification phase presents sample pages of the application and explains its components. In the testing phase, the model was tested using a sample set of users, and the feedback proved that the developed model had better acceptability and ease of access.

Author contributions

Conceptualization, LM and YG; methodology, LM; software, YG; validation, LM, YG; formal analysis, LM; investigation, LM; resources, YG; data curation, YG; writing—original draft preparation, LM and LG; writing—review and editing, LM and YG; visualization, YG; supervision, LM; project administration, YG; funding acquisition, LM and YG. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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