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SCENARIO-BASED ON LEARNING ACTIVITIES DESIGNED TO PROVIDE INTERACTIVE EXPERIMENTAL LAB AT SCIENCE DISCIPLINES

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Abstract

Even if online and distance learning options were accessible before COVID-19 it wasn't appreciated and incorporated properly within educational process. The unwelcomed situation created by COVID-19 pandemic it has brought a lot of uncertainties, challenges and set a milestone for online educational process. In the context of suspended face-to-face activities, teachers had to solve a great challenge: to teach online experimental activities at science disciplines. Hence, everyone had to adapt and to found in a short period of time the best solutions. If delivering theoretical aspects was easier to implement, experimental activities became quite provocative at that moment. This paper presents solutions that we found and implemented in our science classes during COVID-19 pandemic period and the new perspectives that arose from this experience. Considering that online learning represents a powerful educational solution and having in view possible future emerging situations (pandemic, extreme climatic conditions etc) that may affect face to face learning, we intend to develop and implement in our science disciplines a virtual laboratory under the name "Hybrid Environmental Engineering Laboratory for exercising practical skills".

Key words: *education; online learning; virtual laboratories (VLs).*

INTRODUCTION

On 11th of March 2020, the World Health Organization officially declared COVID-19 a global pandemic, due to the rapid increase in the number of cases and the high risk of spreading the infection globally (Cucinotta & Vanelli, 2020). As a reaction, the European Union and the authorities of the Member States, including Romania, have taken a series of measures to protect the population from the Coronavirus: movement and travel restrictions, quarantine of localities, strict hygiene measures, the distribution of medical and protective equipment, and even the temporary stoppage of certain economic activities.

Among all these, the education sector was one of the worst affected, as more so as online teaching was not implemented before. Universities, including those from Romania, have been forced to switch to online education and to reconfigure all educational practices from face-to-face interaction to online environment. The sudden and unplanned transition to online learning has created a number of challenges for students and for faculty academic staff, this being the new standard teaching method for almost an entire academic year (Merill, 2020; De Witt, 2020) and the only available manner to continue educational process in this given situation (Kee & Zhang, 2022).

The closure of all educational institutions worldwide marked the beginning of a period full of challenges for the entire education system.

The COVID-19 pandemic has significantly accelerated the digital transformation of our societies and these processes, once triggered, are expected to gain more and more speed.

This paper highlights the challenges of the rapid transition to online and distance education, the identified solutions to surpass the educational crisis and to sustain at acceptable standard the educational process.

CHALLENGES

When educational activities were suspended in the third week of the second semester of University of Agronomic Sciences and Veterinary Medicine Bucharest (USAMV of Bucharest) studies until the end of the academic year (June 2020), appeared the necessity to reorganize "on the fly" the modality of operation, educational resources, pedagogical techniques and the interaction between teaching staff, students and colleagues.

The transition was characterized by a short but intense period of reorganization and regrouping of the educational process. Learning and teaching has been structured to effectively meet the challenges of fulfilling the most important university's mission: providing education. Empowering teachers to deliver distance education while ensuring and engaging students was vital in managing the transition and successfully completing the academic year. Having a strong instructional design team working closely with academic staff has proven to be essential to the effective transition to online and distance learning (Hodges et al., 2020).

The most prominent and impactful change was the necessity of rapid adaptation to provide education by finding the best solutions at that time. While all disciplines were affected by this sudden change, science teaching was particularly disrupted due to the hands-on and research-based nature of laboratory activities.

Linking theory and practice has always represented a manner that helped students to develop their logical reasoning, thinking skills, to understand many processes and concepts, but before year 2020 this was not a challenge.

In this crisis situation, difficulties arose with some courses that required laboratory training of students.

Theory classes were held online using e-learning platforms and videoconferencing applications, meanwhile for experimental disciplines were used virtual labs (VLs) existing on different platforms at that moment (Table 1).

During the COVID-19 pandemic period, the VLs were adopted as the only possible manner to experiment scientific concepts which otherwise were presented satisfactorily in the real laboratories.

In addition, after pandemic period in universities all over the world the challenge accepted by scientists, informaticians and teachers was to develop VLs suitable to provide education in all circumstances and to integrate technology into the traditional learning environment.

VIRTUAL LABS (VLs)

Literature studies have indicated VLs as an education platform for improving education through the dissemination of laboratory education (Radhamani et al., 2021). These are the digital tools that can be used to provide distance learning for laboratory sessions (Radhamani et al., 2021) without affecting the quality of learning (Toma et al., 2022).

In addition, Vary (2000) defines VLs as "*an electronic workspace designed for remote collaboration and experimentation, or carries out other creative activities, and disseminate results using information and communication technologies*".

During the quarantine and after, due to restrictions, VLs played a crucial role in the higher education sector, this being the only route to continue teaching and learning. Most teachers supported the role of VLs in improving their teaching skills and supporting students to complete laboratory practices without affecting the quality of learning (Raman et al., 2021a; 2021b; 2021c).

VLs cannot completely replace the physical experiments in traditional laboratories. However, in academic environments, virtual and physical laboratories can work together (Achuthan et al., 2017; Vasiliadou, 2020). Furthermore, there are authors that sustain that the best results are obtained when virtual labs and traditional methods are combined (Chan et al., 2021).

Especially during the COVID-19 pandemic, students performed online experiments without time limitations, received instant feedback, familiarized themselves with health and safety regulations, repeated experiments and self-evaluated (Vasiliadou, 2020). Also, by using VLs, they are engaged with technology and prepare more productively for their physical laboratories (Breakey et al., 2008). Moreover, studies (Hawkins & Phelps, 2013; Usman & Huda, 2021) provide evidence that VLs enhance comprehension and motivation, students being more interested by this approach.

Even if before the pandemic there were many concerns regarding the VLs and the efficiency of this approach regarding learning (Tatli & Ayas, 2010; Mikropoulos & Natsis, 2011; Herga & Dinevski, 2012; Hawkins & Phelps, 2013; Ratamun & Osman, 2018; Nais et al., 2019) the real value of this study method was found when access to university laboratories was restricted due to the quarantine and the pandemic of COVID-19.

In Romania, before COVID-19 period were reported several VLs for university studies and their effectiveness was evaluated on the basis of students' attitudes and results (Nedelcu and Saru, 2003; Trifan, 2011; Craifaleanu et al., 2014; Popescu, 2015; Marusteri et al., 2019). After pandemic period, because of difficult situations that occurred during educational process and had to be surpassed, VLs were developed by different teams (Craifaleanu & Craifaleanu, 2022; Vergara et al., 2022; Schneider et al., 2022).

1. Benefits of Using Virtual Labs

In the following section are summarized the main advantages of VLs.

- ***Availability***

The great advantage is that worldwide students who learn remotely or are restricted due to pandemic situations or other emerging cases may access the virtual experiments any time they need from all places. Virtual experiments are very effective in the learning process since application of certain scientific concepts is possible from places all over the the world.

- ***Accessibility*** for people those are not able to participate at classes because of health issues or incapacity (Heradio et al., 2016).

- ***Personal experience***

In VLs, experiments are performed individually or in small groups, similar to real-world labs.

- ***Better student safety***

Some experiments that are dangerous or difficult to perform in real laboratory are possible to be conducted in VLs. Using virtual experiments, disappear the deal with toxic or radioactive chemicals and other hazards and in this approach, laboratory accidents are totally avoided (Heradio et al., 2016; Chan et al., 2021).

- ***Flexibility in learning process***

Students can access VLs from different types of devices from any location whenever they want.

- ***Quick feed-back***

Due to rapid feed-back, students can repeat the experiments so many times as it is necessary to understand the scientific concepts.

- ***Better immersion***

Difficult to understand concepts are more easily presented in the VLs by using animations and simulations (Tüysüz, 2010); some processes that may unfold during a long period of time in real life may take minutes using simulations.

- ***Reduced economic and time costs***

VLs alleviate the space, time and cost constraints associated with traditional labs and are an effective teaching aid. Planning the experiments, the preparation of solutions used in the experimental protocols is time consuming and, in some cases, the lack of instrumentation or worse in the laboratory strongly limits the development of experiments (Tüysüz, 2010).

2. Cons of Using Virtual Labs

Beside advantages, there are some negative aspects associated with VLs.

- ***Difficult development of VLs***

Development of virtual experiments requires a multidisciplinary team made of subjects with different expertise areas, and the optimization of the resulted product is associated with the harmonization of the ideas provided by each team member, which in many cases is time consuming. Consequently, the design and implementation of a certain scientific concept into a virtual laboratory experiment is difficult, time consuming, suppose high costs but the advantage is that the end product it will be used by many students and if it is necessary, it may be updated easily.

- ***Reduced direct human interaction***

One of the main negative effects of VLs is that it reduces direct student-student as well as student-teacher interaction, given that most of the time, communication between them is done electronically.

- ***Student may behave like a viewer without implication, with lack of responsibility and seriousness*** (Potkonjak et al., 2016; Salmeron-Manzano & Manzano Agugliaro, 2018). Immediate feedback improves student engagement.

- ***Student insensitivity***

Student may become insensitive to failures and danger in certain real situations.

- ***Danger of excessive individualism of students and teamwork skills decrease*** (Salmeron-Manzano & Manzano Agugliaro, 2018).

- ***Limited sensory experience***

In a real laboratory, during experiments students may observe some unusual smells, noises that could influence their perception and contribute to scientific knowledge. Tactile experiences are completely missing.

IMPLEMENTED SOLUTIONS

1. Virtual simulation provided by different platforms

During academic year 2020-2021, as attempt to find a solution to the impossibility to attend physically to experimental activities associated with environmental disciplines it was used different virtual substitutions.

In Table 1 is presented an analysis of virtual simulations found on different platforms that are suitable to be aligned to environmental courses.

After evaluation of all found resources (Table 1) for environmental disciplines, precisely for course "Polluting sources, processes and products" most appropriate was found the "Labster Virtual Lab Experiments" because it offers virtual immersive laboratories, besides a complete set of teaching resources and allowed to enroll students.

Labster is a company dedicated to developing virtual laboratory simulations designed to stimulate students' natural curiosity and highlight the connection between science and the real world. Labster gave us the opportunity to explore virtually for a month without cost the desired experiments without problems of access and especially of danger.

Regarding students' opinion related to interactivity provided by Labster, they appreciated immersive nature, 3D reality and application. They found it to be a suitable substitute for experiments in the physical laboratory and considered that in a critical situation as COVID-19 created, this was the best manner to achieve educational goals.

Table 1. Simulations suitable for environmental sciences

No	Site name	Attributes and characteristics	Disciplines	Free/Subscription
1.	**Amrita Vishwa Vidyapeetham**	- suitable for students, high-school students, engineering scientists; - simulations-based experiments can be accessed remotely via internet; - each virtual lab is composed from sections: theory, procedure, self-evaluation, animation, assignment, reference, feed-back.	Electronics&Communications; Computer Science & Engineering; Electrical Engineering; Mechanical Engineering; Chemical Engineering; Biotechnology and Biomedical Engineering; Physical Sciences; Chemical Sciences.	- open access; - user must create a free account
	https://vlab.amrita.edu/index.php; https://www.vlab.co.in/			
2.	**eduMedia**	- interactive resources for learning science; - available in 8 languages; - suitable for teachers, students (elementary and secondary levels), libraries and individuals, publishers; - interactive simulations, quizzes and videos sorted by subject and by grade; - easy to access.	Life Sciences; Environment; Technology; Math; Physics; Astronomy; Chemistry.	- free of charge without registering; - subscription to secured access authorize projections in classroom/public.
	https://www.edumedia-sciences.com/en/			
3.	**Gizmos**	- interactive math and science lab simulations; - suitable for grades 3-12; - library with over 500 simulations where students can graph, measure and compare; - contain STEM* cases where students assume the role of scientist which must solve a situation.	Mathematics; Science	- 30 days free trial account with full access to all labs and simulations
	https://gizmos.explorelearning.com/			
4.	**HHMI BioInteractive**	- case studies, high quality videos, interactive media; - suitable for high school and undergraduate students; - available in English and Spanish.	Science	- free
	https://www.biointeractive.org/			

5.	**Labster**	- suitable for universities and high school; - interactive experiments, quizzes, supplemental resources (manuals, videos etc); - educators can track student performance from their gradebooks, and students can stay on top of their work; - easy to access by everyone; - easy to obtain support from Labster experts.	Analytical Chemistry, Anatomy & Physiology, Animal Physiology, Biochemistry, Biology, Biotechnology, Botany, Cellular and Molecular Biology; Chemistry; Civil Engineering & Material Science; Classical Mechanics; Demo; Developmental Biology; Earth and Space Science; Earth Science; Ecology; Electricity; Engineering; Environmental engineering; Evolution and Biodiversity; Forces and Motion; Foundation Concepts in Science; General Biology; General Chemistry; General Physics; General Science; Genetics; Inorganic Chemistry; Lab Safety; Microbiology; Modern Physics; Nutrition; Organic Chemistry; Oscillations; Pharmacology; Physics; Physiology; Universal Scientific Skills; Waves	- 30 days free trial full access; - institutional subscription (cost: $49 -$99).
	https://www.labster.com/			
6.	**LabXchange**	- free online platform for science education created at Harvard University with support from de Amgen Foundation; - available in 14 languages; - contains videos, simulations, case studies, question tests, textbooks.	Biological sciences; Health science; Physics; Chemistry: Science & Society; Mathematics	- free account
	https://www.labxchange.org			
7.	**Merlot**	- a database with animations, case studies, on-line courses, textbooks, presentations, quizzes, simulations; - suitable for all levels starting with pre-K up to professional.	Art; Business; Education; Mathematics and Statistics; Science and Technology	- free membership
	https://www.merlot.org/merlot/			
8.	**NMSU**	- eight modules that help students learn basic laboratory techniques and practice methods used by lab technicians and researchers in a variety of careers, using specific food science lab processes.	Science; Food Safety	- free
	https://virtuallabs.nmsu.edu/index.php			
9.	**NOVA Labs**	- a digital platform that engages teens and lifelong learners in games and interactives that foster authentic scientific exploration; - on the basis of an account, students will be able to track and save their progress, achieve goals in the games and interactives.	Science	- free
	https://www.pbs.org/wgbh/nova/labs/			

10.	**OLabs**	- a platform that hosts experiments for students from classes 9 to 12; - contain theory, procedures, animations, videos, simulations, self-evaluation, resources.	Physics; Chemistry; Biology; Maths; English	- free upon registration
	https://www.olabs.edu.in/			
11.	**PhET Interactive simulations**	- interactive simulations; - PhET sims are based on extensive education research and engage students through an intuitive, game-like environment where students learn through exploration and discovery; -PhET has received a lot of awards (https://phet.colorado.edu/en/about)	Physics; Chemistry; Math; Earth Sciences	- free and open source
	https://phet.colorado.edu/			
12.	**PNX Labs**	- virtual labs for companies and education institutions (college, university); - virtual labs are suitable to train students to operate complex industrial equipment; - virtual labs for STEM* education.	Physics; Chemistry; Biology; Materials Science; Engineering Mechanics; Manufacturing; Nanotechnology	- demos are for free
	https://pnxlabs.com/			
13.	**PraxiLabs**	- suitable for students and educators; - unlimited access to STEM* simulations; - highly interactive and immersive 3D simulations that mimic real-life labs.	Biology; Chemistry; Physics	- free account; - PraxiLabs free plan offers 20 fixed experiments in the fields of science; - in paid plans, the user can go through all the simulations portfolio available and select what he needs.
	https://praxilabs.com/en/virtual-labs			
14.	**The Concord Consortium - Molecular Workbench** -	- software for designing and conducting computational experiments across science; - visual, interactive simulations for teaching and learning science.	Physics; Chemistry; Biology; Biotechnology; Nanotechnology.	- free and open source
	http://mw.concord.org/modeler/			
15.	**The Concord Consortium – online resources**	- scientific accurate virtual labs; - based on STEM* education (merging science, technology, engineering, mathematics); - accessible from elementary level to higher education; - registration as a student; - registration as a teacher to access several key features (creating classes, assigning activities, saving work, tracking student progress); - easy to access.	Chemistry; Earth&Space; Engineering; Life Science; Mathematics; Physics	- free registration
	https://learn.concord.org/about			

***STEM** = Science, Technology, Engineering, and Mathematics.

2. Developing environmental engineering laboratory education: hybrid virtual lab for exercising practical skills

There are significant educational advantages that can be achieved when high quality virtual tools are fully integrated next to traditional laboratory sessions within curricula, each complementing and consolidating learning from the other. In engineering education, there are still many areas waiting to be digitized and to offer hybrid interactions with users in meaningful manners.

Therefore, transferring traditional labs to the hybrid of real and virtual forms are urgent and timely, particularly in the current situation of post-pandemic recovery.

In order to develop digital competences and surpass the similar crisis situations as pandemic, in 2022 USAMV of Bucharest financed project Hybrid lab of Environmental Engineering for practical skills (HybridPraxisLab) which will be implemented by our team and which consists in creating virtual laboratory (environmental sciences) with experiments that can be mapped successfully with environmental disciplines.

The main aim of the project is to facilitate and improve laboratory education by implementing new technical and pedagogical models of laboratory conduct through the development of a new model of virtual access laboratory.

The project is intended to cover mainly but not only the thematic area of the course "Pollutant Sources, Processes and Products" and covers 28 hours of practical lessons in which students develop experiments to apply the theoretical concepts acquired during the course. Experiments developed on the HybridPraxisLab will be used in these lab hours during the second semester of the academic course 2022/2023.

With the help of simulations from the virtual laboratory HybridPraxisLab, students will:

- work with real-life case studies;
- use laboratory equipment;
- conduct experiments;
- understand and deepen different scientific concepts with the help of experiments.

HybridPraxisLab will be an interactive, immersive learning environment designed to prepare students for real-life experiments, supplement and complement the practical experience by “teleporting” the physical “Environmental Engineering Laboratory” into the virtual environment. Students will practice and become confident in handling equipment before entering the real lab. It is very important for relating theory to practice, so that the students can develop engineering judgment and understand how process behavior can be captured using mathematical models and interesting graphical user interfaces.

The specific objectives of the project are to:

- develop graduates prepared for the demands of the future by experiencing a real working environment through virtual training;

- delivery of a complete learning management system around the virtual lab where students can use the various tools for learning, including additional web resources, lab manual, step-by-step procedures, animated demonstrations and self-assessment;

- increase student engagement in learning practical techniques and understanding of key concepts through a blended approach that complements real, face-to-face lab experiences with virtual lab experiences;

- determine the impact of integrating components of the hybrid approach on students' learning experience using educational research methods and modern pedagogical theories.

Water quality testing is the module developed for now from HybridPraxisLab.

Learning outcomes include:

- **gaining** knowledge of the parameters used to determine water quality;
- **mastering** laboratory methods;
- **acquiring** specific water quality testing skills;
- **acquisition of** practical experience in collecting and analysing water samples;
- **understanding** how human activities affect
- **water quality and watersheds**.

A representation of the virtual lab interface is shown in the Figure 1.

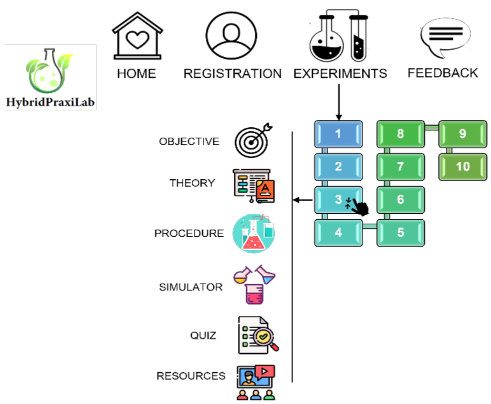

Figure 1. Virtual lab interface

Access to HybridPraxisLab is free for students upon registration with email and password.

The protocol that a student may follow to access any of the ten **Experiments** is presented below:
- student has to choose from a number of topics related to laboratory practice;
- the aim and significance of experiment is found in **Objective** section;
- the experiment description and theoretical aspects are depicted in **Theory**;
- the experimental part is detailed step-by-step in **Procedure** section;
- the simulation of the chosen experiment is found in **Simulator** area;
- evaluation of the acquired information after simulation into virtual laboratory is achieved using an assessment test from **Quiz** section;
- supplemental information (lists of books, videos, links) are found in the **Bibliographic resources** area (Figure 1, Figure 2).

The experiments that are virtualized into HybridPraxisLab laboratory are:
1. Lab safety virtual lab.
2. Protocol for sampling and transport of water samples.
3. Pipetting: selecting and using micropipettes virtual lab.
4. Acids and bases.
5. Determination of pH for different water samples.
6. Preparation of solution: from salt to solution.
7. Determination of turbidity for different water samples.
8. Determination of chlorides in different water samples.
9. Determination of dissolved oxygen in water.
10. Mass spectrometry virtual lab: exploring the instrument.

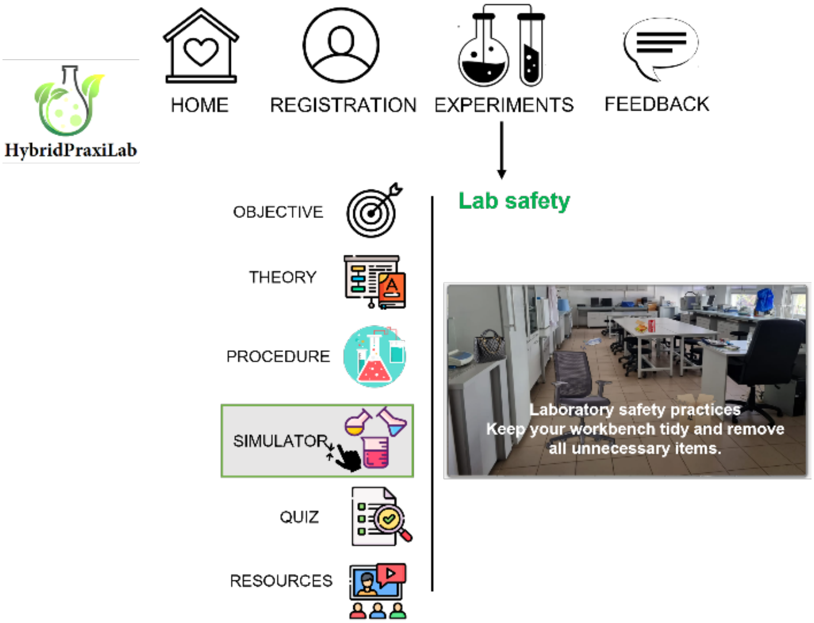

Figure 2. Laboratory safety simulation

The potential benefits of the virtual experiments from HybridPraxisLab are:
- improved understanding, knowledge retention and transfer of learning through visualization;
- active learning using interaction;
- continuous testing of learning outcomes;
- delivery of continuous feedback;
- providing self-paced instruction;
- provide feedback to the instructor on concepts that are not well understood so that remedial action can be taken;
- integrating basic concepts with virtual labs.

The efficacy of the virtual experiments from HybridPraxisLab and feed-back from students will be evaluated after second semester of the academic year 2022/2023 on the basis of questionnaires/surveys and considering the obtained results at exams, this information being disseminated in a future paper.

CONCLUSIONS

The “digital impulse” of the educational area was facilitated by the COVID-19 pandemic and it is an action now considered unstoppable. Having in view the unexpected and until now, unique situation created by COVID-19 it is mandatory for all educational staff to find new solutions to provide education on all circumstances (quarantine, extreme climatic conditions etc).

Today’s students are “the digital generation” and nowadays, the request for engineers with employability skills and digital competences has increased. Using VLs gives students the chance to develop critical, innovative thinking, digital enrichment, teamwork, communication and key employability skills, all of which are highly valued in today's job market.

After pandemic period, everyone has understood that VLs are a part of the future in learning and it will used as a supplement to hand-on laboratories and traditional teaching manner. Universities has realized that distance is not a problem to continue the educational process and not only in special situations and emergencies.

It has been accepted that online education is here to stay and the implementation of VLs into education is a fact that provide its evolution. HybridPraxisLab, a virtual lab created as a necessity to overcome the critical situations, will be easy to use and can be accessed by students and teachers 24/7, 365 days a year, removing all geographical, mobility and time barriers. It will provide a more efficient learning experience for students and make more resources and technology available. Therefore, students can improve their STEM education skills in a safe virtual lab, no matter where they are.

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