Online-Journals.org

iJOE International Journal of Online and Biomedical Engineering

iJOE | eISSN: 2626-8493 | Vol. 20 No. 2 (2024) | OPEN ACCESS

https://doi.org/10.3991/ijoe.v20i02.43099

PAPER

Study of Free Fall Using an Ultra-Concurrent Laboratory at the University

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ABSTRACT

This article presents the results of the educational use of an ultra-concurrent laboratory during the second semester of 2022, in the Cisale Chair of the Common Cycle of the University of Buenos Aires in order to strengthen the experimental scenarios and quality of the process in the teaching of physics. For this purpose, a quantitative descriptive study in which 68 students participated was carried out. This allowed establishing a significant scenario with the implementation of the ultra-concurrent free-fall laboratory to enhance experimental development in physics teaching processes. It is concluded that remote laboratories are promising technologies for teaching physics at the university level. However, it should be clarified that the impact of an educational innovation does not only depend on the technology used, but also on the didactic design with which it is approached.

KEYWORDS

ultra-concurrent laboratories, free fall, experimental activity

1 INTRODUCTION

Remote laboratories (RLs) are educational resources that integrate *software* and *hardware* tools and allow experimental activities to be carried out remotely.

In other words, they make it possible for students and teachers to carry out this type of practice from anywhere and at any time, operating the instruments remotely through a graphical interface. This technology supported practical laboratory work in different educational contexts during the COVID-19 pandemic and is presented as a possible alternative for post-pandemic science education.

The RLs can be classified into real-time laboratories (RTLs) and ultra-concurrent laboratories (ULs). The latter can be used by a large number of students and are, therefore, of particular interest. In recent years, different ULs have been developed for the study of chemistry [1,2], physics [3] and electronics [4]. Some of the advantages of these laboratories are the possibility of working with large groups, the

Navarro, E.A., Moya, C.N., Lizano-Sánchez, F., Arguedas-Matarrita, C., Ley, C.M., Idoyaga, I. (2024). Study of Free Fall Using an Ultra-Concurrent Laboratory at the University. *International Journal of Online and Biomedical Engineering (iJOE)*, 20(2), pp. 4–15. https://doi.org/10.3991/ijoe.v20i02.43099

Article submitted 2023-07-13. Revision uploaded 2023-10-24. Final acceptance 2023-10-31.

opportunity to repeat the experience many times, the reduced cost of reagents and the consequent lower environment impact [16].

This paper focusses on the study of an UL for teaching physics which deals with the case of free fall, typically included in the kinematics chapters. The general characteristics of the laboratory and some aspects related to the perceptions of its implementation in a massive and heterogeneous university course are presented.

1.1 Ultra-concurrent Laboratory Architecture

The ULs are based on a set of recorded experiences with real equipment. The recordings are automated, resorting to the open source WebLabLib library and to *software* solutions for experience optimisation, patented and commercialised by the company LabsLand [5]. The typical architecture of this type of laboratories is shown in Figure 1.

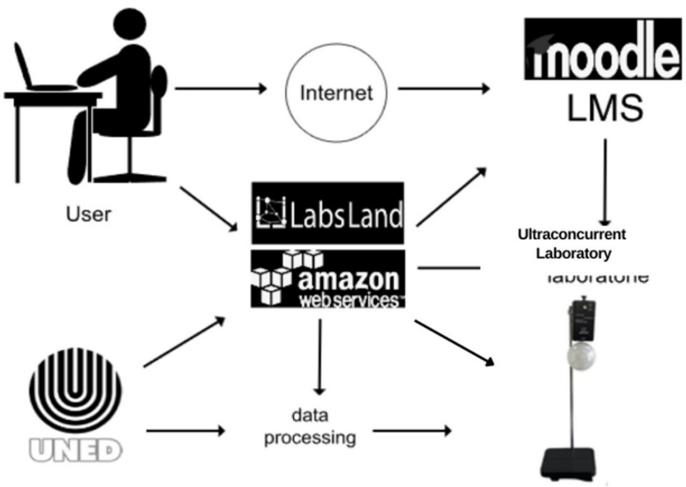

Fig. 1. Ultra-concurrent laboratory architecture

In these laboratories, the user enters and interacts through a graphical interface. Access can be through an LMS (learning management system) platform, for which the following is available:

- Web server: in charge of displaying the audio/video of the laboratory, the actions that can be performed on the laboratory and the results of these actions.
- Remote Laboratory Management System: it allows the different laboratories to be shared, provides analysis of use and provides different educational supports; in this case, it is managed through LabsLand.
- Laboratory: equipment that is remotely controlled or manipulated.

The laboratories are developed by different institutions or organisations that design and execute the experience that is automated to be federated by LabsLand so that they are available to users in different parts of the world.

1.2 Description of the ultra-concurrent free fall laboratory

The laboratory analysed in this work is a joint development of Universidad Estatal a Distancia (UNED) and LabsLand [6], a company that offers a global network to connect RLs from different institutions.

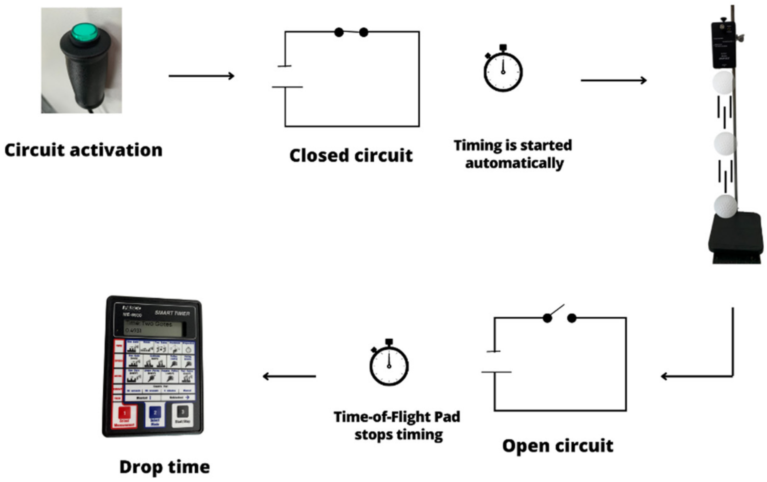

Fig. 2. Schematic of the free-fall LR

The laboratory was developed with free fall equipment (Figure 2), which consists of an electrical circuit that is activated when a user presses an electric switch. The timing is then automatically started and at the same time an object is dropped. When the object hits the Flight Pad, the circuit closes and timing stops [7] and the flight time is measured.

1.3 Ultra-concurrent free fall laboratory interface

In order to use the laboratory, it is necessary to access the LabsLand platform and select the free fall experience. Once inside, a countdown time of 20 minutes is enabled and three commands are presented. The first displays conceptual information related to the experimental activity, a schematic configuration of the experience and a tutorial to support it. The second one allows you to set the desired height and select the sphere of interest. The third shows two views, a frontal view that shows the whole experience and another one that allows to pay attention to the moment immediately before the sphere reaches the end and to read the time of the fall of the object (Figure 3).

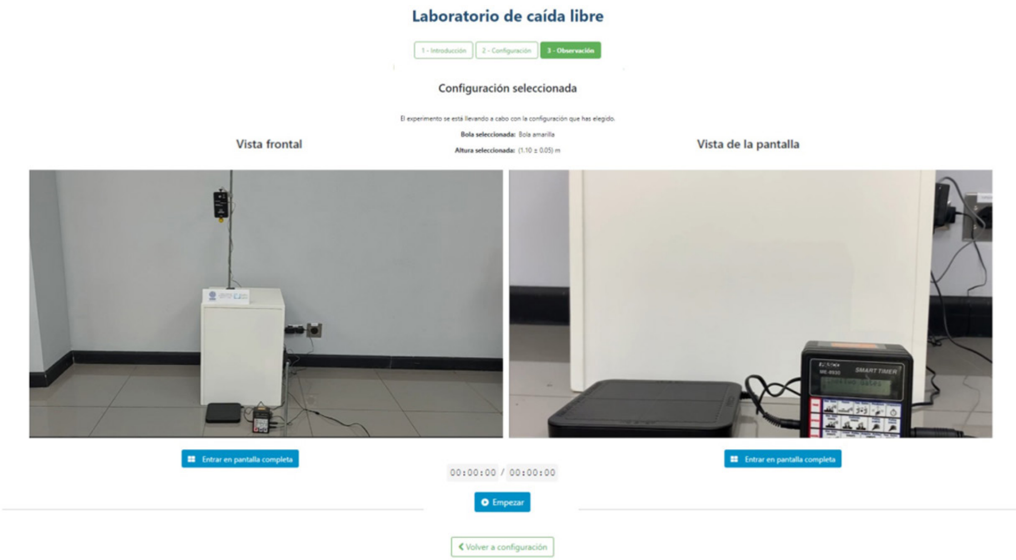

Fig. 3. Ultra-concurrent free fall laboratory development interface

1.4 University education with remote laboratories

The main challenge for the inclusion of RL in universities lies in the adoption of ubiquitous teaching models based on the design of immersive transmedia narratives, so that students can work collaboratively and play a central role in their learning processes.

The extended laboratory model (EL) [8] provides a framework for the design of teaching proposals with RL. It proposes a didactic approach of conducting experimental activities in hybrid education scenarios. In this model, the experimental activity is any action planned by the teacher with the aim of promoting the learning of concepts, procedures, and attitudes through study and observation of work variables. This particular type of activity can be carried out through different resources, which can be classified according to their level of complexity and the type of interface [9], the latter being understood as a construct where social interactions take place. The different resources, which include traditional laboratories, simulations and remote laboratories, must act synergistically within a comprehensive didactic proposal, in order to promote socially and professionally relevant learning.

In this framework, RLs are a valuable resource for working with the complexity and uncertainty of experimental data and the control of variables. They could also promote collaborative work, peer discussion, and decision-making [10].

1.5 Educational implementation of the ultra-concurrent free fall laboratory

The free fall UB was implemented as part of the teaching proposal of the physics course and Introduction to Biophysics course of the Cisale Chair of the Common Basic Cycle (CBC) of the University of Buenos Aires (UBA). This is the first introductory course in physics for undergraduate courses in the area of Biomedical Sciences.

The educational implementation was carried out during the year 2022. Activities were performed synchronously and face-to-face in a class corresponding to the mechanics unit. Students accessed the UL through the virtual classroom of the course available on the Moodle platform, using their own digital devices (mobile phones, tablets, and notebooks).

The students worked in small groups of 4 to 6 people with a specially designed activity in which they had to measure the fall times from various heights for 4 spheres of different diameters and masses and compare the values obtained. Some of the questions that guided the experimental activity were:

1. What is the relationship between the mass of a sphere and its fall time?
2. What is the relationship between the diameter of a sphere and its fall time?
3. What is the relationship between the height from which a body is dropped and the time it takes to fall?
4. What differences do you find between the values obtained experimentally with the remote laboratory and the values predicted by the model of uniformly variable rectilinear motion? How do you explain these differences?

After the group work, there was a group discussion guided by the teacher in which the results were discussed.

Subsequently, the experimental activity was evaluated with an exam question in which data obtained with the free-fall UL were presented and the students were asked to analyse them, based on what they had worked on in class and the experience obtained with this remote design to work remotely [11].

2 METHODOLOGY

The method corresponds to a quantitative approach [11] and pursues a descriptive purpose about the use and perception of students about the implementation of the UL free fall in the physics and introduction to biophysics course of the Cisale Chair of the Common Basic Cycle of the University of Buenos Aires (CBC-UBA). The course corresponds to a first university course in physics for undergraduate students in the biomedical sciences and deals with the study of disciplinary chapters such as kinematics, mechanics and heat. The professors of the chair work collegially, serving the educational needs of about 8000 students per year who in the two semesters are divided into class groups of 70-100 students each.

Participants in this study were 68 students aged 18-22 years in the second semester of 2022, who were part of 4 class groups chosen to represent the two teaching shifts: morning shift (10 a.m. to 1 p.m.) and afternoon shift (2 p.m. to 5 p.m.). Participation was voluntary and did not interfere with the normal activities, membership data was coded and treated confidentially.

Firstly, to study the use of the free fall UL, data from the platform provided by LabsLand were used: number of uses per student and day-time-zone of use.

Secondly, to identify the devices used to connect to the UL and to know different aspects of the students' perception, an instrument adapted and validated by Idoyaga and collaborators [12] based on Heck's proposal [13] was used. It consisted in two sections:

1. The first section included a closed question of the checkbox type, to find out the devices used by students to access the UL. The following (non-exclusive) options were proposed: Computer, Tablet, Mobile phone and Laptop.
2. The second section consisted of 13 Likert-type statements (Table 1) to indicate the degree of agreement (1: totally disagree, 2: partly disagree, 3: neither disagree nor agree, 4: partially agree, 5: totally agree) on three aspects: usability of the UL, perception of their own learning and satisfaction.

Table 1. Statements usability, perception and satisfaction of the instrument

		1	2	3	4	5
i. Usability						
E.1	I found the ultra-concurrent free fall laboratory easy to use.					
E.2	During my work in the ultra-concurrent free fall laboratory I was able to perform the desired actions without any problems.					
E.3	The information available of the ultra-concurrent free fall laboratory helped me to manipulate the conditions of the experimental activity.					
E.4	The session time of the ultra-concurrent free fall laboratory (20 minutes) was sufficient to complete the experimental activity.					
ii. Learning Perception						
E.5	Working with the ultra-concurrent free fall laboratory helped me to better understand the contents of the class.					
E.6	Working with the ultra-concurrent free fall laboratory gave me a better understanding of how to work in the physics laboratory.					
E.7	Working with the ultra-concurrent free fall laboratory helped me to present, manipulate and organize how to work with experimental data.					

(Continued)

Table 1. Statements usability, perception and satisfaction of the instrument *(Continued)*

		1	2	3	4	5
E.8	Working with the ultra-concurrent free fall laboratory improved my ability to design, present and interpret how experimental data works with tables and graphs.					
E.9	Working with the ultra-concurrent free fall laboratory helped me to solve the activities in the exercise and problem guide.					
iii. Satisfaction						
E.10	In general, I am satisfied with the ultra-concurrent free fall laboratory that I have used in this physics course.					
E.11	Working with the ultra-concurrent free fall laboratory was relevant to my studies in this physics course.					
E.12	I would like to see other ultra-concurrent laboratories available in this physics course.					
E.13	I was motivated by working in the ultra-concurrent free fall laboratory in this physics course.					

The instrument was applied through the virtual classroom once the course was completed and descriptive statistics were used for data analysis using Minitab software, LLC version 19.1.0.1.

3 RESULTS

3.1 Use of the free fall UL

The 68 participating students used the Free Fall UL 178 times in a two-week period, which is an average of 2,62 uses per student (Table 2).

72% of the uses (128) were recorded outside school days and hours, 20% (36) between 17:00 to 23:59 and 29% (51) from 6:00 to 9:59 on weekdays and 22% during the weekends (39).

3.2 Access devices

The most widely used device for accessing the UL free fall (Figure 4) was the cell phone. 68% of the participating students (46/68) indicated they used this device. In addition, 31% of participants (21/68) used desktop computers, 21% (14/68) used laptops and 10% (7/68) used tablets.

Table 2. Percentages of uses by days and hours with the free fall UL

Schedule	Days							Total by Bands
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	
0:00 to 5:59 h	0	0	0	1	1	1	0	3
6:00h to 9:59h	3	2	10	15	21	18	1	70
10:00h to 16:59h	8	3	13	18	8	5	5	60
17:00h to 23:59h	4	5	10	8	9	2	7	45
Total uses by day	**15**	**10**	**33**	**42**	**39**	**26**	**13**	**178**

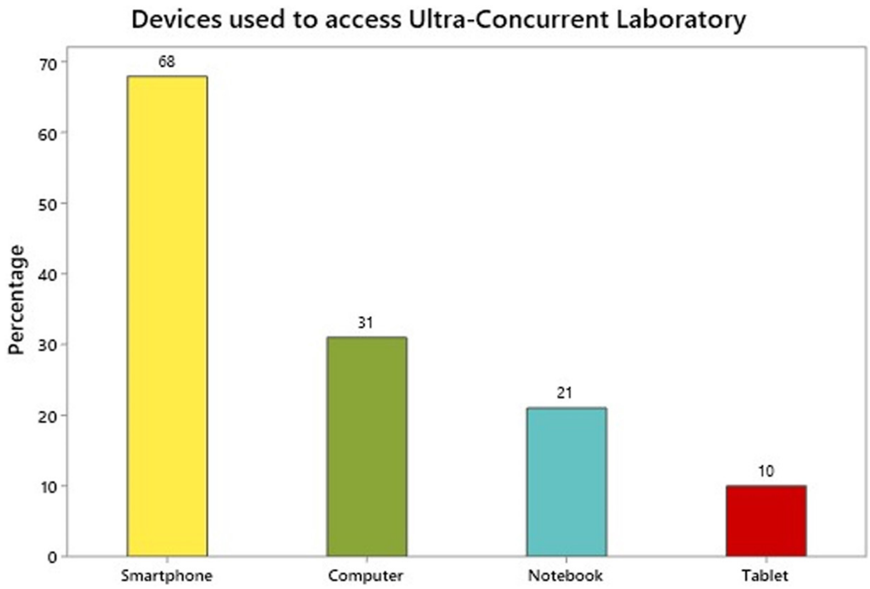

Fig. 4. Devices used to access UL for the people of the CBC-UBA

3.3 Usability

Participants' responses on usability show a similar behaviour to the statement E.1 ease of use, E.2 (possibility to perform desired actions) and E.3 (information available), with a high percentage in the four levels (partially agree) and 5 (totally agree): 89%, 88% and 82%, respectively. On the other hand, statement E.4 (time available per session) registers a percentage of 52% for levels 4 and 5 (Figure 5).

These results show that usability was highly valued and the least appreciated aspect was the availability.

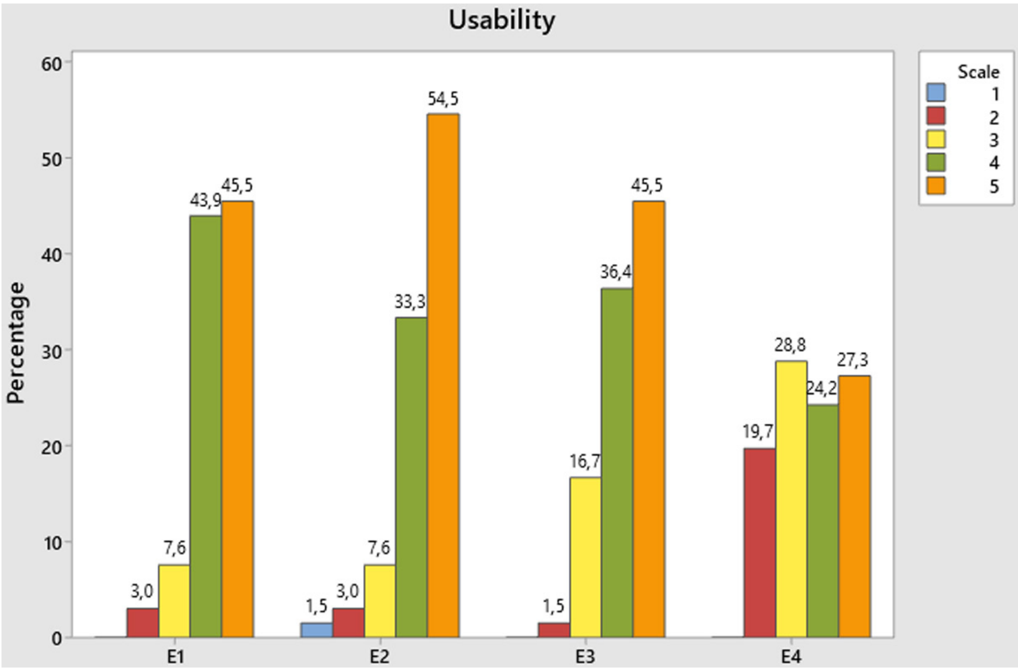

Fig. 5. Perception of the usability of free fall UL with the population of the CBC-UBA

3.4 Perception of learning

In the enquiry on the perception of one's own learning, the responses to statements E.5 (understanding of experimental work), E.7 (handling empirical data), and E.9 (solving problem situations) had a similar behaviour. For levels 4 (partially agree) and 5 (totally agree) 82%, 85%, 82% and 84%, respectively, were recorded. Statement E.8 (making tables and graphs) showed a slightly lower percentage (70%) for levels 4 and 5 (Figure 6). It is worth mentioning that in the case of statement E.8 there was a higher percentage of responses in level 3 (neither agree nor disagree) than for the other statements.

These data show that students recognise high levels of learning in the different aspects surveyed.

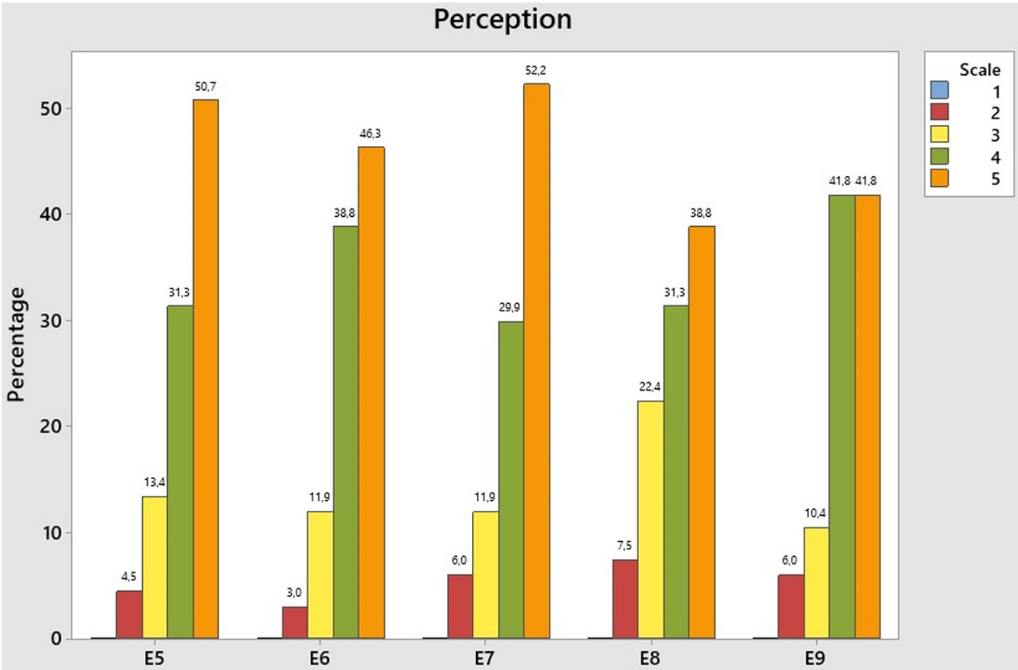

Fig. 6. Learning perception of the free fall UL with the population of CBC-UBA

Satisfaction. Regarding the satisfaction survey, the responses to statements E.11 (relevance), E.12 (demand for more UL), and E.13 (motivation) show a similar behaviour. For these statements, levels 4 (partially agree) and 5 (totally agree) recorded 72 %, 80% and 75%, respectively. Statement E.10 (overall satisfaction) recorded a higher percentage for levels 4 and 5: 93% (Figure 7).

These results show a high level of student satisfaction with the incorporation of the Free Fall UL as a student-centred educational innovation through an easy, flexible and always available environment [14] at the CBC-UBA.

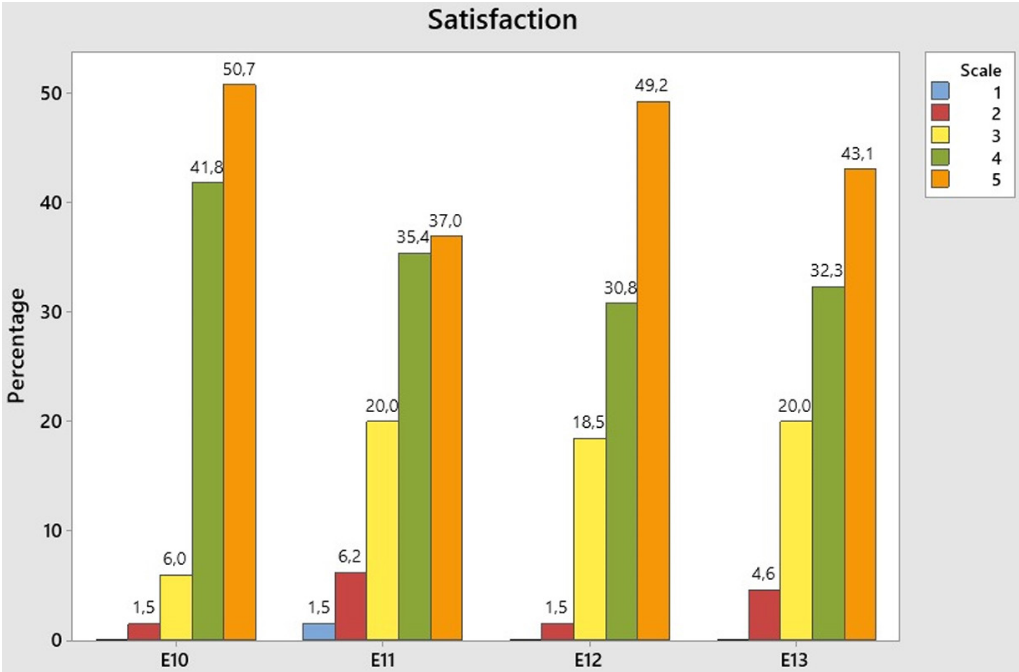

Fig. 7. Freefall UL satisfaction with the population of the CBC-UBA

4 DISCUSSION AND CONCLUSIONS

This paper provides an insight into some aspects of the introduction of remote laboratories into higher education practice. In particular, it focusses on the perception of students in a massive first-year physics course in biomedical sciences. This is of interest as the incorporation of technologies to enhance learning in different contexts needs to be carefully studied and documented. Even more so on the face of the establishment of hybrid educational modalities which necessarily require a transformation of the ways of working.

The study of the incorporation of RL and any other technology aimed at supporting experimental activities in digital environments becomes strategic for the strengthening of didactic models designed to guide the teaching of natural sciences in current times. In other words, this type of research results is useful for promoting reflection on how to recover the experimental nature of these disciplines in distance or hybrid educational proposals.

The results of this study show that the students were able to repeat the experimental activities in the proposed UL. This can be understood as tending towards self-regulation of learning and the promotion of study autonomy, as it would eventually allow different modifications to be introduced in the different repetitions. In this line, the use of the UL in the physics course and introduction to biophysics course aims to follow the guidelines of the EL model that tends to make the student become the manager of his or her own learning [16].

The results of this study show the ubiquity of student learning practices with the UL, since access is recorded from different devices, especially portable, such as mobile phones, and at times outside of class, at night and on weekends. Again, this is consistent with the didactic model adopted for the innovation, which proposes the temporal extension of experimental activities in science teaching.

According to the evidence collected, the Freefall laboratory was easy to use. The graphical user interface allowed students to perform all desired actions without complications and provided dynamic access to all necessary information. However, some of the participating students stated that the time available to perform the activity on the platform was limited. These findings can reinforce and/or reorient the design and development of this type of technology in order to facilitate its implementation in different performance scenarios for teachers and students [15].

Data on participants' perception of their own learning were very encouraging in terms of learning disciplinary content, understanding experimental work, solve problem situations, handling empirical data and, to a lesser extent, understanding tables and graphs. This makes the UL a promising alternative for work in this specific context, which should be further explored with other methodologies that go beyond learners' perceptions and consider all other aspects of innovation implementation.

Among the results obtained, the students' high level of satisfaction with the inclusion of the UL in their educational practices stands out. This is probably linked to the greater autonomy and independence that this type of practice allows with respect to traditional ones. In the same sense, all this can be thought of as evidence that the CBC-UBA or similar contexts are conducive to educational innovation with UL.

In conclusion, and as a corollary, it can be said that this study reinforces the idea that RLs are promising technologies for teaching physics at university. However, it should be clarified that the impact of an educational innovation does not only depend on the technology used, but also on the didactic design in which it is inserted. Thus, ULs, as a central part of the proposals that follow the EL guidelines, could promote learning, increase student autonomy and recover the experimental nature of the discipline in post-pandemic educational scenarios.

5 ACKNOWLEDGEMENTS

This work was carried out in the framework of the projects FSED_2_2020_1_163647 of the National Agency for Research and Education of Uruguay and PDE_03_2023 and PIDAE_34_2022 of the University of Buenos Aires.

This article is part of the results of Project PROY0049-2021 registered with the Vice-Rectorate for Research of Universidad Estatal a Distancia.

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