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Assessment of Student and Teacher Perceptions on the Use of Virtual Simulation in Cell Biology Laboratory Education

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Abstract: Virtual laboratory simulations (VLs), particularly in Biology education, are gaining popularity. This study focused on assessing students' and teachers' perceptions of VLs, developed by Labster, in a first-year undergraduate cell biology course. The evaluation involved surveys and interviews with 352 respondents. Findings indicate that over 90% of students found VLs user-friendly and visually engaging. However, around 60% noted the need for significant technical resources, which could limit accessibility. Over 80% of students reported that VLs increased their motivation, autonomy, interest, and confidence. While only 72% viewed them as potential replacements for traditional labs, more than 90% preferred using VLs as preparatory material for practical sessions. Teachers generally agreed with these perceptions, emphasizing the need for technical support for effective use. They suggested that VLs are better as pre-lab activities rather than full replacements. Both students and teachers recognized VLs as beneficial for academic performance and learning attitude but noted limitations in technical support for home use. The consensus was that VLs are most effective as complementary material before in-person lab sessions.

Keywords: virtual laboratory; simulation; cell biology; remote teaching; online teaching

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1. Introduction

Advancements in technology have revolutionized the way science is taught and learned. Virtual learning environments, such as virtual laboratory simulations (VLs), have increasingly become popular tools in the field of science education. VLs have been defined as computer-based software that can simulate scientific experiments and allow students to interact with them in a virtual environment [1]. VLs have been widely adopted as an alternative to physical labs, in different educational institutions across the globe, and at different levels of education, from middle or High school [2,3] to Higher Education [4–7].

VLs have been used in a context of various scientific disciplines, such as engineering, physics, chemistry, among others [1,8–10]. At the biological science context, VLs are widely used [4], especially in topics such as the cell, molecular biology, ecology, introductory biology, evolution, biotechnology, genetics, and interdisciplinary topics (e.g., Biochemistry) being introductory, cell and molecular biology the most addressed topics [11].

Although VLs have been used from several years ago, during COVID period, they have played an important role in education as students and teachers were unable to attend physical laboratories due to social distancing measures and because the education establishments were physically closed [12–15]. There is an increasing interest to analyze the advantages and limitations of using these kinds of tools in teaching science, and the principal impacts in effective learning and perceptions amongst the users, such as students and teachers. Among the main advantages of using VLs, and of virtual learning in general, it has been indicated that they can be accessed from anywhere with an internet connection, enabling distance learning and equal opportunities for all students. They also allow increased flexibility in terms of scheduling, saving the travel time of students and teachers [16], and saving time doing the laboratory [8]. Additionally, virtual lab simulations encouraged students to 'make mistakes', examining the consequences and learning from them, helping them to field more confidence, and allow students to repeat the experiment until they fully understand the concepts [8,13,17]. In addition, VLs might have the potential to reduce costs and save limited resources in educational institutions such as those associated with infrastructure, human resources, equipment maintenance and supplies, a very important fact in developing and under-developed countries with limited educational budgets [1,18–20].

One of the most important potential benefits of VLs is to enhance student engagement and motivation to learn. Coleman and Smith [21] found that virtual laboratory simulations positively impacted student engagement and understanding of complex scientific concepts in comparison to traditional laboratory activities, and they also have a long-term impact on student learning. However, Reece and Butler [22] compared a face-to-face laboratory to a low fidelity virtual laboratory biology simulation in undergraduate students and found that there were no significant differences on motivation or final grades between the groups. In the same line, Makransky et al. (2019), compared the equivalence of using desktop virtual reality science simulations at home compared to using them under supervision of a teacher in the classroom, showing that home and classroom groups did not differ significantly on post-test learning outcome scores, or on self-report measures of intrinsic motivation self-efficacy. In addition, the equivalent outcomes were not dependent on prior knowledge or goal orientation [23].

Although VLs could have several potential advantages over traditional physical labs, they have some limitations and researchers and educators still debate whether they can fully replace hands-on lab experiences. Some critics argue that virtual lab simulations may not fully replicate the complexities of real-life laboratory scenarios and therefore cannot replace entirely traditional laboratory activities; for instance, research reports have found that virtual laboratory tools do not effectively teach most generic laboratory skills, such as how to use specific items of equipment [24–26]. They also lack conditions for developing social interaction skills, a general disadvantage faced by the students while taking online courses [16]. From another point of view, students claimed the lack of "sense" involved was more likely to make them forget [8], or others indicated that they experienced technical problems when using VLs, which caused frustration and influenced negative attitudes towards them [5].

Byukusenge et al. (2022), in a recent review about the effectiveness of virtual laboratories in teaching and learning biology, through a meta-analysis concluded that conceptual understanding is the learning outcome most enhanced when using virtual labs; they improve students' motivation, self-efficacy, and attitudes towards learning biology topics, especially in difficult and abstract biology topics related to cell and molecular biology [4]. In fact, cell or molecular biology are the most widely used topics in the virtual laboratories in the field of Biology, probably related to if the topics are abstract, dynamic, hard to visualize, and composed of complex relationships between elements [11]. For example, VLs have a significant impact on increasing students' understanding of the nerve cells' structure and functioning, and they even increased performance levels in nervous concepts [2].

It seems that the effectiveness of virtual labs, and how students and teachers perceive these instructional tools, largely depends on the way they are used. There are different ways for using VLs: in addition to purely theoretical courses, as a replacement for hands-on exercises, as supplements to the regular hands-on laboratories, as a pre-laboratory tool, or as using VLs in the class with teacher supervision [14,23].

Some authors suggest that VLs are well-suited to be used as a supplement or as a preparatory tool because they have the potential to increase pre-laboratory preparation to ensure more confident students and potentially improve progression of the conducted laboratory exercises [5]. The same perception is shared by students, who indicated that they preferred to use VLs as a supplement or preparatory tool rather than in replacement for the physical laboratory [8].

In this context, it is relevant to ask about the perception of students in relation to the use of VLs. One of the VL programs widely used is Labster© (Somerville, MA, USA), a virtual Laboratory interactive simulation designed to place students in real-world scenarios, immersing them in an interactive learning environment where they practice lab skills and visualize theory. Bonde et al. (2014) investigated whether Labster© laboratory simulations could stimulate a higher degree of motivation for studying biotechnology topics in High School and the Technical University students. They found that gamified laboratory simulation can significantly increase both learning outcomes and motivation levels when compared with, and particularly when combined with, traditional teaching. They suggest that simulations could be used as a homework assignment as a pre-laboratory or post-laboratory activity in combination with traditional teaching [3]. In the same line, Dyrberg et al. (2017) studied motivation and attitude towards virtual exercises using Labster© VLp in university biology students. After completing virtual laboratory cases, students declared feeling significantly more confident and comfortable operating laboratory equipment, but they did not feel more motivated to engage in virtual laboratories compared to real laboratories [5].

Our principal aims in this research was to evaluate how students and teachers from a cell biology laboratory course from the University Andres Bello perceive Labster© simulations in the context of learning, with a focus on four dimensions: the usability of the platform, attitudinal skills for learning, support in learning and impact and benefit of using this virtual tool. We also evaluated the perception among the teachers, based on reflective workshops where they were asked to give their opinion of using Labster© simulations in the course, guiding the discussion through general questions.

2. Materials and Methods

The following section presents a comprehensive description of the teaching innovation model, including the context in which it was conceived, the research methodology utilized, and the approach employed for evaluating the results.

2.1. Innovation Context

For the cell biology laboratories, curricular approaches are defined as the specific strategies and methods employed in the design and delivery of laboratory activities, aimed at achieving the learning outcomes. These approaches are intended to facilitate the development of students' understanding of cell biology concepts, enhance their laboratory skills, and promote critical thinking and problem-solving abilities.

The present study was focused on the development and implementation of an innovative approach in the use of virtual labs, where virtual activities were used in combination with face-to-face activities. During the second semester of the year 2022 (August–December), a cohort of 400 first-year undergraduate students at the Universidad Andrés Bello (UNAB), Chile, was divided into eighteen laboratory sections, all sections experiencing virtual and in-person activities. Traditionally, the UNAB cell biology laboratory course syllabus is organized into six distinct units, each unit associated with specific concepts and laboratory techniques. In this context, we developed a mixed pedagogical strategy that incorporated activities based on laboratory simulations and other traditional face-to-face laboratory activities, in the 50% of the course activities. This program provided students with a valuable hands-on experience in studying the fundamental unit of life—the cell—through a blended approach, whereas traditional cell biology laboratory courses generally are limited only to in-person activities.

2.2. Pedagogical Model Design

The objective of the study was to evaluate the effectiveness of Labster© simulations to enhance learning experiences for students and teachers using them in the cell biology laboratory course. To determine which labs would be virtualized, the Labster© catalog was reviewed to see if the contents of the simulations were aligned with the expected learning of the course. Simulated labs were used in the units of solutions, cell chemistry, cell division and fertilization. For this purpose, the syllabus was modified to declare the activities that will be virtual, in addition to aligning the contents reviewed in the simulations and the evaluations associated with these activities with the expected learning of the cell biology laboratory. New study guides were also created for each of virtual laboratories that, in addition to including the theoretical contents, also provided a detailed guide for the use of the simulators, stating how the contents of the simulators are aligned with the theoretical contents of the guide, so that students perceive these activities as a support for learning the subject and not only as a digital tool. The students carried out the three virtual laboratories remotely, synchronously, and always with simultaneous teacher assistance.

Finally, and in this context, the perceptions of students and teachers after using simulators were evaluated to determine their effectiveness in achieving the expected learning outcomes.

2.3. Research Methodology

As an initial, exploratory study, this research used a quantitative approach to evaluate students' perceptions of their learning experience. This study received the approval of the ethics committee of the Universidad Andrés Bello, Life Sciences Faculty. The evaluation was based on a perception survey that was validated by a panel of experts prior to use, and it was constructed based on previously published surveys [27–29]. The survey had 19 questions that were distributed in four dimensions, including usability of the platform (4 questions), attitudinal skills for learning (5 questions), learning support (6 questions), and the impact and benefit of using the virtual tool (4 questions). The survey assessed the students' degree of agreement with the statements. The survey was conducted during the last face-to-face session of the course and the Formsite® app (www.formsite.com (accessed on 27 November 2022); Chicago, IL, USA) was used to collect the responses. A total of 400 first-year undergraduate students participated in the study. Of these, 352 (88%) of the participants responded correctly to the study surveys, indicating a high response rate. The data collected in the survey were recorded and analyzed anonymously. The 19 survey items were rated on a six-point Likert-type scale [30]. The scale ranged from "strongly disagree" to "strongly agree", with a numerical value assigned from 1 to 6, respectively. The results obtained from the Likert-type rating scale were presented as the percentage of responses for each question, and the reliability of the survey was assessed using Cronbach's alpha (α), as previously describe for this kind of research [27].

Finally, to collect the opinions of the teachers who participated in these courses, a qualitative approach was used through group semi-structured interviews. The questions were like the student's survey and were classified and analyzed in the same dimensions: usability of the platform, attitudinal skills for learning, learning support, and the impact and benefit of using the virtual tool. Three focus-group interviews' sessions were conducted, the first focus group into the first month of the course, the second in the middle and the third at the end of the semester. The results of these interviews were systematized in a final report that provided information that allowed relating the students' perception with the teachers' opinion on the use of virtual laboratories in cell biology.

For analysis purposes, our results were grouped and analyzed by each dimension declared for both students' perceptions survey results and teachers' opinions in the semi-structured interviews, and are presented as a comparison of perceptions for each dimension.

3. Results

Survey results on student perceptions were presented as a percentage of responses for each question, which were categorized into the survey dimensions described above. For each dimension analyzed from survey results, we correlated with the teacher's perceptions that they declare after performing all the virtual laboratories activities of the academic semester. An overall descriptive analysis of the total results shows that perceptions from both students and teachers are highly positive about the feature of using virtual simulated cell biology laboratory activities.

3.1. Perceived Ease-of-Use

Questions related to how students perceive the ease of use of the virtual laboratory activities of the Labster© platform were included in this dimension (Table 1).

Table 1. Percentage of responses on perceived ease-of-use dimension questions.

Question	1 "Strongly Disagree"	2	3	4	5	6 "Strongly Agree"
1. Labster activities are easy to use.	2.35% (8)	1.47% (5)	4.71% (16)	7.35% (25)	25.29% (86)	58.82% (200)
2. The technical requirements for the use of Labster (computer/software/internet connection) are a limitation for the development of the simulation activities.	9.12% (31)	10.59% (36)	11.18% (38)	20.00% (68)	20.88% (71)	28.24% (96)
3. The time of execution of the Labster activities is adequate to develop them during the laboratory.	3.24% (11)	4.41% (15)	6.76% (23)	12.35% (42)	25.00% (85)	48.24% (164)
4. Labster activities present visual characteristics (attractive, simple design, intuitive) that facilitate their use.	2.35% (8)	1.47% (5)	2.65% (9)	6.47% (22)	19.71% (67)	67.35% (229)

On the general perception of use, more than 90% of the students surveyed (91.7%; *n* = 311) considered the simulation activities to be easy to use. Furthermore, over 93% (*n* = 318) of the students considered that this ease of use was positively associated with the Labster© activities presenting attractive visual features in their design.

From the students' point of view, the activities were not only easy to use in general terms, but they also considered that the execution time of the activities was adequate in the context of laboratory time, with 85% (*n* = 291) of positive responses on this point.

Interestingly, the students' appraisal of whether virtual simulations presented a high technical requirement for their implementation as a teaching activity showed a high percentage of positive responses (61.12% of the total students' responses), suggesting that access to adequate equipment, such as the type of computer and internet connection, was a determining factor for the implementation of this type of activity in a laboratory class.

In this line, an analysis of the teachers' opinions correlated with the results of the students' surveys, highlighting that a good Internet connection and equipment seemed to be determinant for the correct implementation of this type of laboratory activities, with a perception that the Labster© virtual laboratory simulation was not suitable for all types of operating systems of the devices used by the students to connect to the activities, such as cell phones and computers. As an example, here are some quotes from teachers related to this dimension analyzed:

> *". . . (the virtual laboratory activities) it's a good add-on, but it has implementation issues such as connectivity".*
>
> *("Teacher12" opinion in focus group 1)*

> *"The problem is that if they have a bad internet connection, they can't download the software, so they lose time and get stuck in some steps. There are students who could finish in forty minutes and other students were late and could take an hour and twenty minutes".*
>
> *("Teacher8" opinion in focus group 2)*

> *"We detected that students do not always have a good internet connection and that they presented particular problems when using Mac or iPad devices".*
>
> *("Teacher4" opinion in focus group 2)*

3.2. Attitudinal Competencies

In this dimension, questions on motivation and autonomy, confidence in what students learned through the virtual lab activities, and improving students' participation in subject lessons were classified (Table 2).

Table 2. Percentage of responses on attitudinal competencies dimension questions.

Question	1 "Strongly Disagree"	2	3	4	5	6 "Strongly Agree"
5. Doing Labster activities improves your motivation for learn	4.41% (15)	2.94% (10)	5.29% (18)	14.12% (48)	16.47% (56)	56.76% (193)
6. Doing the Labster activities improves your autonomy to learn	4.71% (16)	3.53% (12)	5.88% (20)	12.65% (43)	21.76% (74)	51.47% (175)
7. Doing the Labster activities improves your interest in the subject	5.29% (18)	4.41% (15)	5.59% (19)	10.88% (37)	21.76% (74)	52.06% (177)
8. Doing the Labster activities improves your confidence in what you learn	5.00% (17)	4.12% (14)	5.00% (17)	10.88% (37)	27.94% (95)	47.06% (160)
9. Doing the Labster activities improves your participation in the subject lessons	5.59% (19)	4.12% (14)	8.53% (29)	13.24% (45)	20.00% (68)	48.53% (165)

In terms of motivation, most of students positively appraised that performing Labster virtual lab activities improved their motivation for (87.35%) and their autonomy to learning (85.88%), which correlated with both a highly positive response frequency (84.70%) on improved students' interest in a cell biology laboratory lesson and with improved students' participation (81.77%) on this subject. Moreover, 85.88% of students positively perceived that doing virtual lab activities improved their confidence in what they learned when they performed the Labster activities as a virtual lab session. Taken together, these results suggest that performing virtual lab sessions using Labster-simulated activities improved different attitudinal competencies that are important for students' learning process.

Interestingly, the opinions of teachers on the development of attitudinal competencies when using these virtual simulation Labster© activities were dissimilar to the results obtained in the student survey, where they highlighted that the motivation to learn improved when using this strategy; however, they added that this was only achieved depending on the degree of maturity of the student to commit to their online learning process:

> *"Yes, the online system works, but you have to have a certain maturity and unfortunately here first-year students don't have the maturity to be responsible for their own learning".*
>
> *("Teacher3" opinion in focus group 1)*

> *"It increases motivation because as a guiding teacher you definitely measure, and you can clearly see that students have paid attention to the simulations and respond to questions in an active way. They are connecting the ideas when you talk to them about the topic, they participate and say Ah! that is why we are going to do this and that is when they are landing the idea and complementing it".*
>
> *("Teacher9" opinion in focus group 2)*

> *"What we or the students lack is how we manage to engage them for the proper performing of the virtual activities".*
>
> *("Teacher6" opinion in focus group 2)*

3.3. Perceived Learning Support

Results of the questions regarding if performing Labster© virtual labs activities improved the students' perceptions about supported learning (Table 3) showed that most of the students agree with the idea that doing these simulated activities improves their overall academic performance in a cell biology lab subject. Interestingly, 89% of the respondents perceived that virtual lab activities improved their understanding of theoretical concepts related with the subject, with a similar percentage of students perceiving that also these virtual lab activities improved the acquisition of practical abilities, which was declared as a procedural learning outcome in the laboratory subject syllabus.

Table 3. Percentage of responses on perceived learning support dimension questions.

Question	1 "Strongly Disagree"	2	3	4	5	6 "Strongly Agree"
10. Labster activities improves your understanding of the theoretical concepts of the subject.	4.41% (15)	2.65% (9)	3.82% (13)	9.71% (33)	23.24% (79)	56.18% (191)
11. Labster activities improves your acquisition of practical skills (material handling, use of equipment, development of procedures) related to the subject.	8.53% (29)	6.47% (22)	6.18% (21)	14.71% (50)	22.35% (76)	41.76% (142)
12. Labster activities improves your academic performance in the subject.	2.94% (10)	2.65% (9)	4.12% (14)	10.29% (35)	17.94% (61)	62.06% (211)
13. The assessment questions that are included within the Labster activities contribute to verify your learning of the activity contents.	2.06% (7)	2.94% (10)	3.53% (12)	8.82% (30)	23.24% (79)	59.41% (202)
14. The assessment questions that are included in the Labster activities are appropriate for the exigency level (or personal dedication) involved in the activity.	2.94% (10)	1.47% (5)	4.12% (14)	10.29% (35)	23.53% (80)	57.65% (196)
15. Developing Labster activities improves their preparation for other subject evaluations (lab reports, multiple choice tests, among others).	4.12% (14)	3.82% (13)	5.88% (20)	12.65% (43)	26.18% (89)	47.35% (161)

In terms of the perceived improvements in the assessment performances of the students, 90% of the students positively appraised that performing the Labster© activities improved their academic performance in the subject, both in the assessment question within the simulated activities (91.5% of responses) and in other assessments in the subject, like laboratory reports or multiple-choice tests (86.2%). This result is in line with the observation that most of the students agreed with the question related to the exigency level of the questions proposed by the simulated activities themselves, perceiving that this level of exigency was adequate with the subject content and/or their personal dedication.

Taken together, these results suggest that the use of virtual lab activities like ones developed by the Labster company for a cell biology laboratory subject improved the students' academic performance, which was related to a higher understanding and confidence (Table 2) in what they were learning, both theoretical concepts and practical skills.

In this dimension, the teachers' opinion differed in part from the results of the student survey. On the one hand, teachers positively valued the use of this tool, identifying that it helped the learning of the theoretical concepts associated with the subject. However, in their perception, this type of activity, when carried out virtually, did not contribute to the acquisition of the practical skills required for laboratory work.

> *"In lectures, it is observed that they are more familiar with the contents to apply in experiments or practical activity".*
>
> *("Teacher3" opinion in focus group 1)*

> *"In my opinion it helped because we force the student to review the contents of the subject, since they have to read, they have to go to the definitions.*
>
> *They do the whole simulation. And this helps a lot to improve the grades".*
>
> *("Teacher4" opinion in focus group 1)*

> *"Labster works quite well as a complement to the face-to-face practices in the laboratory, because this way the student comes with a learning already acquired to then put it into practice".*
>
> *("Teacher2" opinion in focus group 2)*

> *"... In this experience, the use of the Labster application I think it works well, because the students bring notions, for example, of instruments, equipment, vocabulary, it facilitates the development of the lesson".*
>
> *("Teacher2" opinion in focus group 1)*

> *"It does not allow at all the development of the skills that a student should have in the laboratory...the Labster provides learning for the theoretical part".*
>
> *("Teacher4" opinion in focus group 1)*

3.4. Perceived Impact and Benefits

Considering that there is currently a growing use of digital tools for teaching–learning processes in higher education, students who took the cell biology laboratory course virtually using Labster' VLs activities were asked about their opinions regarding the possibility of using this type of virtual activities in future versions of this and other courses that could incorporate the use of digital teaching as a pedagogical strategy. The results (Table 4) show in general terms that a large percentage of students' positive appraised the use of these digital tools.

Table 4. Percentage of responses on perceived impact and benefits dimension questions.

Question	**1 "Strongly Disagree"**	**2**	**3**	**4**	**5**	**6 "Strongly Agree"**
16. I would use Labster in the future as a virtual lab activity to replace the face-to-face lab.	12.35% (42)	5.29% (18)	10.00% (34)	12.65% (43)	11.76% (40)	47.94% (163)
17. I would use Labster in the future as an activity during a face-to-face lab.	10.29% (35)	8.53% (29)	9.12% (31)	15.00% (51)	14.71% (50)	42.35% (144)
18. I would use Labster in the future as a supplementary material, for use prior to a face-to-face lab.	4.71% (16)	1.76% (6)	3.24% (11)	5.59% (19)	19.71% (67)	65.00% (221)
19. I would use Labster in the future as supplementary material, for use prior to theory lectures.	3.82% (13)	2.35% (8)	4.12% (14)	7.94% (27)	20.00% (68)	61.76% (210)

With respect to whether the use of virtual laboratory activities could replace a face-to-face laboratory subject, 72% of the students surveyed positively perceived the use of these virtual activities as a replacement for a traditional laboratory. In addition, a similar percentage of the responses shows that the possibility of using these virtual activities during a face-to-face laboratory session in traditional format was also positively valued by the students. However, it is important to highlight that both questions (Q16 and Q17) show the highest frequency of students who strongly disagree with the incorporation of this type of activities as a replacement of a face-to-face laboratory, which suggests that the use of these virtual laboratory activities as a pedagogical strategy that allows changing the realization of this type of subjects to a virtual or hybrid modality of education should be analyzed in greater depth.

When students were asked about their perception of the use of these virtual laboratory simulation activities as complementary material to be used prior to the face-to-face practical session, over 90% of the students' responses were positive. Comparing this result with the perception of using virtual activities as a replacement strategy for the classroom laboratory, the results suggest that students are inclined to prefer the use of this type of digital activities as complementary material to the classroom session, associated with a flipped-classroom model of teaching.

Finally, the students' perception was highly positive when considering the use of these virtual laboratory activities as a complementary material to prepare for traditional theoretical lectures, which suggests that the use of these simulated activities can easily be extended to subjects which have no practical or lab activities in their curricula based on students' perceptions. The teachers' perception of these ideas concluded from the students' opinion was quite similar, in relation to the fact that the application of these virtual simulation strategies reinforces the necessary concepts as a complementary activity:

> *"When the student arrives at the laboratory it is seen that he has already had a previous concept, he has already had a little bit of concepts and it is like very well complemented with the practices that are done in the laboratory, that is, it is the strategy finally is well focused as a flipped classroom".*
>
> *("Teacher1" opinion in focus group 2)*

> *"(Labster) is a complement to the practical activity, in no case does it replace it, but it accompanies it and helps it in a good way for the learning process".*
>
> *("Teacher5" opinion in focus group 2)*

Based on teachers' opinions, there is a consensus in relation to the valuation of the use of this type of virtual activities by the students, in that it enhances learning methodologies such as the inverted classroom, but it would not be a good tool to replace the face-to-face learning activities in hands-on laboratories.

4. Discussion

Here, we presented results from exploratory research to assess the perceptions from both students and teachers about the use of VLs, specifically those from Labster® company, as a strategy to achieve learning objectives in a cell biology laboratory, which was changed from a hands-on lab to virtual remote activities. The main findings of our research are summarized in Figure 1. Our study highlights the growing popularity of Virtual Laboratory Simulations (VLs) in the field of science education, especially in Biology. These simulations are seen as advantageous tools that can have a positive impact on student engagement and motivation, and the understanding of complex scientific concepts compared to traditional laboratory activities [4]. However, the effectiveness of VLs and how students perceive them depends on their use [8,16,21,29,31,32]. To evaluate these parameters, our work was based on a mixed research approach that integrated quantitative and qualitative methods in one study, thereby achieving a better understanding of the phenomenon by allowing data triangulation. This type of research was oriented to achieve greater depth and interpretation from the actors involved, giving greater credibility to the results [33] (This is **why we evaluated the perception from teachers and students** in relation to the simulation experience in virtual laboratories in a first-year undergraduate cell biology laboratory course. The students' opinion was based on a perception survey that evaluated four dimensions: **usability of the platform, attitudinal competencies for learning, learning support and impact and benefit of the use of the virtual tool**. On the other hand, teachers' opinions were collected through a qualitative method with semi-structured interviews and their responses were correlated with the quantitative data from the students' survey responses.

The survey revealed several interesting findings. Over 90% of the students found Labster's VLs easy to use, indicating that the platform's ease of use was well rated. In addition, the simulations were considered attractive in their visual design, which likely contributed to student engagement. These results are in line with previously described analyses in which the ease of use is a basic requirement for the application of this type of virtual simulation into the learning processes [7,13,16,21,24]. These results are common between students and teachers' perceptions, reflecting that **both groups highlighted the simplicity of the use of the VLs as an important factor in remote learning.**

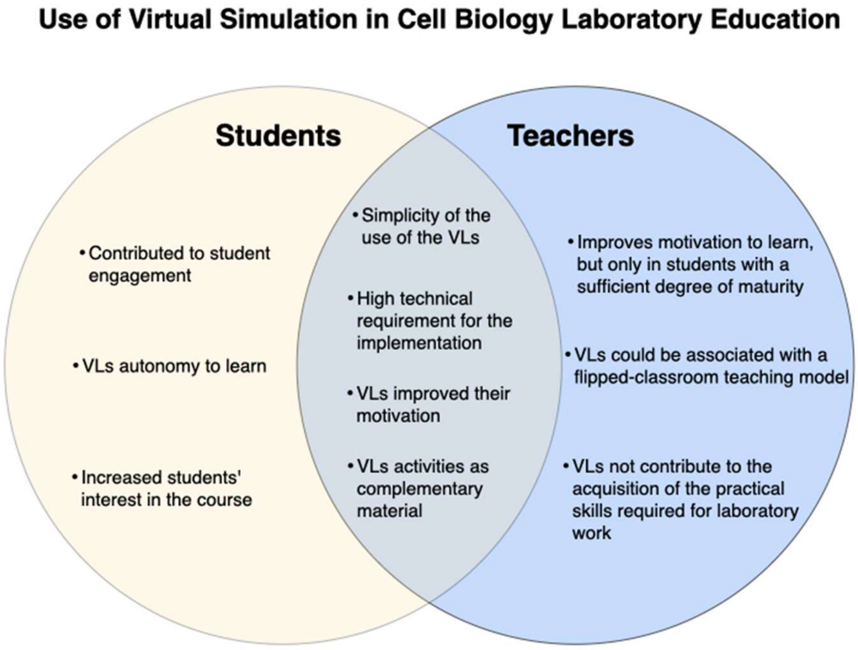

Figure 1. Outline summarizing the key findings from analyzing the perceptions of students and teachers regarding the utilization of simulated virtual activities in a cell biology laboratory. The main ideas are presented in each circle, and the common conclusions to both groups are presented in interception of the two circles.

However, a significant percentage (almost 60%) of the students perceived a **high technical requirement for the implementation of the Labster simulations.** This suggests that access to a suitable computer and a good Internet connection may be a limitation for some students. Teachers' perceptions of Labster VLs agreed that a **computer and good internet connection are required to adequately develop the activities**. Similar results have been found in this area in other studies that have assessed students' perception of using VLs, in which some students demonstrated a non-favorable user experience due to technical issues such as the user interface, slow application performance, lack of responsiveness, and lag time due to data-overloaded web-based applications [5,34]. This has led to frustration and distraction and has had a negative impact on learning [34]. In our experience, Labster simulation cannot be conducted on mobile devices such as cell phones or tablets, which are more accessible devices for students than a good computer. An improvement in this regard would be to be able to perform Labster simulations on these types of devices, since students would be able to access easily and with greater possibilities to connect to the Internet in different places and in a better way. Also, for the **proper application of this methodology in a biological sciences laboratory or in theoretical activities**, a capacitation for the lecturers in terms of software and digital teaching is needed in order to diminish the teachers technostress and other negative perceptions [35,36].

Regarding attitudinal competencies, a large majority (more than 80%) of the students stated that **Labster VLs improved their motivation and autonomy to learn**. It was also found that these simulations increased students' interest in the course and their confidence in what they were learning. Considering these results from students point of view, these results are in line with previously described attitudinal analyses featuring VLs [2–4,8,15,16,28,34], and also are comparable with other virtual strategies implemented, such as gamification [27,37]. In contrast, teachers' opinions regarding the development of attitudinal competencies when using Labster virtual simulation activities differed from the results obtained in the student survey. Teachers emphasized that the use of this strategy improved the motivation to learn, but they also added that this is was **only achieved when students showed a sufficient degree of maturity to commit to their online learning process**. This is a critical featuring which is in particular difficult to achieve in first-year university students, which could be related with the minor human interaction in online or remote activities supported by fully computerized simulations [32]. Indeed, more research should be conducted to determine if VLs improve student self-regulation, which is important to a successfully digital education in the post-COVID-19 era [7,31,38–40].

One of the most critical points in the study of VLs activities and implementation is whether they are successful or not in their replacement of traditional face-to-face activities. In our study, only 72% of the students perceived the virtual activities as a substitute for traditional laboratory experiences. These results relate to what was described in a study by Caño et al., 2021, in which students indicated that they preferred to use VLs as a supplementary or preparatory tool rather than as a substitute for the laboratory [8]. In contrast, more than 90% of the students **preferred to use the Labster ® VLs as supplementary material prior to the face-to-face practical sessions.** These results are consistent with those of other studies in which students accepted virtual labs, but still preferred to use them as preparation for classical labs [15]. Finally, the students' opinions about the use of virtual laboratory activities as complementary material to prepare traditional theoretical classes were highly positive and suggested that the use of these simulated activities can be easily expanded to subjects that do not include practical or laboratory activities in their curricula. On the other hand, teachers shared a similar perception and emphasized that the **application of these virtual simulation strategies reinforces the concepts needed as a complementary activity** that could be associated with a flipped-classroom teaching model. In this line, there have been several reports showing that a blended environment for teaching-and-learning process could be a good way to mix the virtuality of simulation with the presence of the teacher and the face-to-face activities, looking for the proper acquisition of basic sciences skills [12,14,17,29,41–44].

Based on our results, we can conclude that **Labster's VLs were perceived as effective tools that improved attitude towards learning**, which could result in improved student performance. The simulations were easy to use and visually appealing, which increased motivation and autonomy. However, our study also highlighted limitations related to technical support at home, indicating that some students may face challenges due to the technical requirements of the simulations. Therefore, it is reasonable to propose the exploration of strategies to address the identified technical limitations and to assess the long-term impact of using VLs on student performance and knowledge retention in the future.

Overall, our research provides valuable insights into students' perceptions of VL simulations use in the context of science education. We emphasize the importance of considering usability, attitudinal competencies, and the impact of virtual tools on student learning. However, despite the advantages of virtual simulations, they can be used as supplementary material before traditional laboratory sessions and not as a complete substitute for the activity. Future research could explore the specific ways in which VLs can be integrated with traditional laboratory activities to optimize student learning outcomes. Finally, based on the results of this study, a future perspective will be to design and evaluate a learning experience that provides safe and interactive spaces for the practice of cell biology concepts and skills, using a digital resource that complements its learning outcomes and aligns with the graduation profile of sciences and health care undergraduate students.

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