

VIRTUAL LABORATORIES IN THE TEACHING OF EXPERIMENTAL SCIENCES: PERSPECTIVES OF ECUADORIAN INSTRUCTORS

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Abstract

Virtual laboratories offer students the chance to explore scientific phenomena in safe, controlled environments, and to repeat the experiments as many times as they like, which promotes the comprehension of complex concepts. This study examines the level of knowledge, use and perception of virtual laboratories among experimental science educators at the upper secondary education level in Ecuador, as well as the possible differences according to sociodemographic variables. A descriptive quantitative focus was adopted, using an online survey administered to 375 instructors. The questionnaire, consisting of 19 items, was validated by 14 experts and showed a high reliability index ($\alpha = 0.975$). The results reveal that the educators have a positive perception of virtual laboratories, considering them to be useful and versatile instructional tools. However, they continue to be used only occasionally in the classroom, mainly due to the limited knowledge and the lack of training in educational strategies for their effective integration. Likewise, slight differences were identified in the levels of knowledge, use and perception according to age, academic level and the type of educational institution. In conclusion, the findings highlight the need to promote teacher training programs, targeting the educational use of virtual laboratories, designed in a contextualized manner and adapted to the real circumstances of Ecuadorian teachers.

Keywords – Virtual laboratories, Experimental sciences, Teachers, Secondary, Ecuador.

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1. Introduction

Scientific and technological advances, along with social and educational transformations, have redefined the roles in educational settings, influencing how we teach, evaluate and learn (Topalsan, 2020; Falode et al., 2020). In this context, the incorporation of computer technologies, such as simulations and virtual reality, has gained acceptance thanks to its efficacy in science education (Valarezo-Guzmán et al., 2023).

Science education has important limitations in the experimental area, related to the lack of adequate laboratories, modern resources and specialized technical staff (Tüysüz, 2010). This situation is especially

critical in regions like Sub-Saharan Africa, developing countries of Asia and in Latin America. In Africa, the lack or deficiency of laboratory equipment hinders progress in key areas, such as medicine and engineering (Ayeni, 2021). In Southeast Asia, countries like the Philippines are showing significant deficits in infrastructure related to budget limitations and insufficient teacher training in the use of the available resources (Mangarin & Macayana, 2024). Similarly, in Latin American, the lack of experimental means has promoted a focus on rote teaching approaches, a situation that worsens in rural contexts, such as in Ecuador, where the lack of technological infrastructure expands educational gaps even further (Quintanilla-Orna et al., 2025; López-Naranjo & Uquillas-Granizo, 2025).

Furthermore, traditional experimental practices tend to focus on the mechanical reproduction of procedures, which limits in-depth comprehension and conceptual change (Pyatt & Sims, 2012; Vielba-Cuerpo & Castaño-Liedo, 2014). In addition to this are concerns related to safety in physical laboratories, especially regarding the handling of hazardous materials and specialized equipment (Tatli & Ayas, 2013).

In light of these limitations, virtual laboratories (VL) have been introduced as an affordable, effective alternative. These simulations allow students to interact with experimental environments without any risks, facilitating the application of knowledge, decision-making and the visualization of abstract phenomena (Faour & Ayoubi, 2018; Guzmán-Duque & del-Moral-Pérez, 2018). Their low cost, flexibility and capacity to adapt to different context make them valuable tools for both preliminary preparation for real experiments and conceptual reinforcement afterward (Campos-Mera & Benarroch-Benarroch, 2024). They also contribute to active learning and increase student motivation, promoting participation by students in discussions and debates (Lkhagva et al., 2012; Ojo & Owolabi, 2020).

As tools of educational mediation, virtual laboratories (VL) interact dynamically with the different elements of the teaching-learning process, and thus their effectiveness depends on their coherent integration into the instructional proposal (Álvarez & Cabrera, 2020). It is thus essential for educators to have in-depth knowledge of the available options, to select the most appropriate ones for their context and to apply pertinent educational strategies. However, one of the main challenges for their effective implementation continues to be the lack of teacher education (Rocha et al., 2019; Cabrera-Medina et al., 2016).

In this context, teacher training takes on a key role. Various studies have shown that training programs on the use of VL generate positive results, as long as they are adapted to the level of knowledge, experience and perceptions of the educators (Topalsan, 2020; Bose & Humphreys, 2022). However, a gap still exists between the recognition of the potential these tools have and their actual classroom use. This was shown by Heintz et al. (2015) in a European study which, in spite of reflecting positive evaluations by teachers and students, revealed limited implementation of VLs.

Research conducted in specific contexts supports this trend. García-Huamán (2022), in a study on Science and Technology educators in Cusco (Peru), concluded that while a favorable perception exists regarding VLs, the lack of training constitutes an important obstacle for their effective integration. Moawyah and Mahmood (2022), in the southern region of Jordan, identified similar barriers: a lack of knowledge about the benefits of these tools, the lack of training, technical difficulties, insufficient connectivity and adverse institutional conditions, such as overcrowded classrooms and the lack of technical support.

Similarly, Alshaikh (2022) analyzed Biology instruction with VLs in a sample of instructors, finding that, in spite of valuing their potential to develop higher-order cognitive skills, their use was only at an intermediate level. Furthermore, significant differences were identified in the level of use according to the number of training workshops received, which highlights the importance of ongoing and specific training.

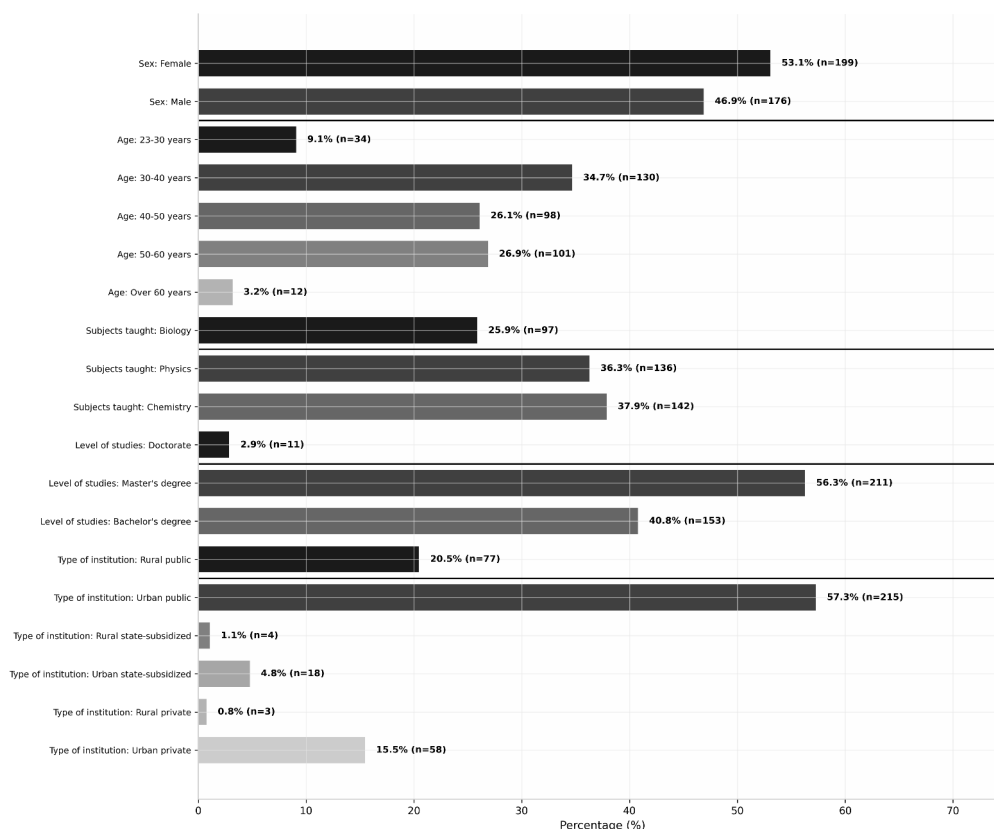
On a similar note, Moreno-Mediavilla et al. (2023) conducted a study on secondary school teachers from every Autonomous Community in Spain, in order to determine the perception of the teachers' digital competence in the use of virtual simulations, analyzing differences based on sociodemographic variables,

use and training. The results showed an average level of self-perception on different aspects of competence, with no significant differences according to gender, age or teaching experience. However, variations were observed according to the area of knowledge, frequency of technology use and the perceived training need. The authors concluded that there is an important need for training on virtual simulations, especially in the search for and selection of appropriate models.

In the case of Ecuador, no studies have been identified that have analyzed the knowledge, use and perception of teachers regarding virtual laboratories in the field of the Experimental Sciences at the upper secondary school level. For this reason, the aim of this research is to diagnose these aspects among Ecuadorian teachers, and to explore the possible influence of demographic variables, such as gender, age, subject taught, previous training and the type of educational institution where they work.

2. Methodology

The research, which was descriptive in nature and had a quantitative approach, was conducted with 375 Ecuadorian educators in higher secondary education who taught experimental sciences. Their demographic characteristics are shown in Figure 1, where it can be observed that they taught Chemistry (37.9%), Physics (36.3%) and Biology (25.9%) courses. The majority of the sample was female (53.1%), between 23 and 60 years of age, and most were teachers between 30 and 40 (34.7%) years of age. More than half had earned a master's degree, while less than 3% held a doctorate. Most worked in urban public institutions (57.3%).



Sex: female; Sex: male; Age: 23-30 years; Age: 30-40 years; Age: 40-50 years; Age: 50-60 years; Age: over age 60; Subjects taught: Biology; Subjects taught: Physics; Subjects taught: Chemistry; Level of studies: Doctorate; Level of studies: Master's degree; Level of studies: Bachelor's degree; Type of institution: Rural public; Type of institution: Urban public; Type of institution: Rural state-subsidized; Type of institution: Urban state-subsidized; Type of institution: Rural private; Type of institution: Urban private

Figure 1. Characteristics of the study sample

Data were collected by means of an online survey based on a Likert-type questionnaire specifically designed for this study and validated by 14 experts (nine with a master's degree, four with a doctorate and one doctoral student), all university instructors with more than five years of experience in the sciences. The validation focused on two criteria: clarity (degree of precision and comprehensibility of the items) and relevance (appropriateness of the items in terms of the research objectives).

The experts graded each item on a scale of 1 (absolutely unclear/irrelevant) to 5 (very clear/relevant), and they had the option to add observations. The results showed high mean scores for both criteria (greater than 4), with low standard deviations (0–1.33 for clarity and 0–0.94 for relevance). Adjustments were made based on their suggestions.

Once the instrument had been validated, it was implemented in Google Forms, including informed consent, demographic questions and 19 items focused on the knowledge, use and perception of virtual laboratories. The pilot test produced a Cronbach's alpha of 0.975, which indicates a high level of reliability. In addition, it was confirmed that the elimination of no item improved the index, and thus all were maintained.

The internal structure of the questionnaire was analyzed by means of exploratory factor analysis (EFA), using SPSS v.28. A minimal load of 0.30 was set for the inclusion of items in a factor. The EFA indicated seven factors, the interpretation of which was based on the joint analysis of the item content and the factor loadings. Table 1 shows the identification of these factors and their correspondence to the questionnaire.

Questionnaire	Items	Factor	Description	Percent of variance explained
Knowledge	1b 1c 1d 1e 1f	F6	Knowledge of specific VLs (except PHET)	2.3
	1a	F2	Knowledge and personal use	12.6
	2			
3				
Use	4	F3	Requirements	6.9
	5			
	6			
Perception	7	F7	Ease of use	2.2
	8			
	9			
	10			
	11	F1	Advantages	47.5
	13	F5	Disadvantages	3.6
	14	F4	Strengths over Physical Laboratories	4.0
	15			
	16			
	17			
18				
19				

Table 1. Factors on the questionnaire

Based on the exploratory factor analysis, it was confirmed that the external structure of the questionnaire is adequately aligned with its internal structure, organized into six dimensions: (1) knowledge and use of

virtual laboratories (VL); (2) requirements for their use; (3) ease of use; (4) advantages; (5) disadvantages; and (6) strengths over physical laboratories.

Once validated, the questionnaire was disseminated online through the educational districts in Ecuador, obtaining a total of 375 responses.

The data collected were analyzed using SPSS v.28 software. In order to explore the possible influence of sociodemographic variables on the responses, the Kolmogorov-Smirnov test was applied, which indicated that the variables did not follow a normal distribution. As a result, the decision was made to use non-parametric tests: the Mann-Whitney U test to compare responses by gender, and the Kruskal-Wallis test to analyze difference according to age, subject taught, level of academic training and the type of educational institution. All tests were carried out with a level of significance of 95% ($p < 0.05$). In cases in which statistically significant differences were identified, the effect size was calculated to assess its magnitude.

3. Analysis and Results

The following section presents the results obtained for each of the items that make up the different sections of the questionnaire, which used a five-point Likert scale ranging from 1 to 5.

3.1. Statistics by Block

3.1.1. Block 1: Knowledge

This block consists of items 1a-1f, 2, and 3-3c. Their intent is to find out about the self-perception of educators regarding their own knowledge of specific VLs, their educational benefits, and about educational strategies for using VLs in experimental science classes.

Table 2 shows the descriptive statistics for the items that make up this block.

Items	Mean	Standard Deviation	Variance
1) Degree of knowledge you have about each of the following Virtual Laboratories (VL):			
a. PhET (https://phet.colorado.edu/es/)	2.41	1.392	1.938
b. Go-Lab (https://www.golabz.eu)	1.95	1.146	1.313
c. Chem Collective (https://chemcollective.org/)	1.89	1.136	1.290
d. Educaplus (https://www.educaplus.org/)	2.62	1.382	1.911
e. Olabs (http://www.olabs.edu.in/)	1.91	1.157	1.339
f. Virtual Laboratory (https://labovirtual.blogspot.com/)	2.35	1.348	1.816
2) Degree of knowledge that you believe you have about the educational benefits which, in general, are offered by Virtual Laboratories (VL)	3.27	1.179	1.391
3) Degree of knowledge you believe you have about the educational strategies for using Virtual Laboratories (VL) in science classes:			
a. Use of VLs by the teachers as opposed to the full class	2.70	1.225	1.501
b. Use of the VLs individually by students with a work guide	2.59	1.218	1.484
c. Use of the VLs by students in small groups with a work guide	2.57	1.219	1.486

Table 2. Descriptive statistics for the items corresponding to block 1

In the knowledge block, teachers especially valued the educational benefits of VLs (item 2), with Educaplus and PhET being the best-known. Although they did not distinguish clearly among instructional strategies, they showed a preference for their directed use by the teacher before the entire class.

3.1.2. Block 2: Use

This block includes items 4, 5a-5c, and 6a-6g. Its aim is to find out the level of use of VLs by those surveyed and the instructional strategies they employ when using them. In addition, it seeks to elucidate the requirements they consider necessary for the use of the VLs in experimental science classes.

Table 3 shows the descriptive statistics for the items that form part of this block.

Items	Mean	Standard Deviation	Variance
4) Degree of use of VLs in your Science classes	2.44	1.220	1.488
5) Degree to which you have employed the following instructional strategies when using VLs in your science classes:			
a. Use of VLs by the teachers as opposed to the full class	2.36	1.209	1.462
b. Use of the VLs individually by students with a work guide	2.16	1.122	1.260
c. Use of the VLs by students in small groups with a work guide	2.19	1.166	1.360
6) Degree with which the following prerequisites must be met in order for you to use VLs in your science classes:			
a. Having technological infrastructure available	3.37	1.462	2.138
b. Being trained in VLs	3.47	1.410	1.988
c. Having the assistance of a teacher-laboratory technician trained in VLs	2.93	1.438	2.067
d. Having fewer students per class	2.91	1.366	1.866
e. Having more time within the institution for class preparation	2.94	1.408	1.983
f. Having VLs that deal with the topics studied in your science classes	3.37	1.413	1.998
g. Having permission from the institution to work with VLs	3.14	1.434	2.058

Table 3. Descriptive statistics for the items in block 2

The educators indicated a low frequency of VL use, which fell between rarely and occasionally (mean = 2.44; SD > 1). This is also reflected in the scarce recognition of instructional strategies, although teacher use in front of the entire class stands out slightly. They identified the following as being the main prerequisites for the implementation of VLs: the need for training, adaptation to the contents and the availability of technology resources.

3.1.3. Block 3: Perception

This block consists of items 7, 8, 9, 10, 11a-11g, 12a-12e, 13a-13f, 14, 15, 16, 17, 18 and 19. Its aim is to find out about the perception of the educators regarding the ease of use of the VLs; their level of accessibility, effectiveness and importance, and the potential attributed to them to achieve the educational objectives in the teaching of the experimental sciences. It also seeks to identify their advantages and disadvantages, their capacity to replace or complement physical laboratories, the degree of willingness on the part of instructors to learn more about VLs; and finally, the potential that is attributed to them for the teaching of Physics, Chemistry and Biology.

Table 4 details the descriptive statistics for the items corresponding to this block.

The perceptions of educators regarding VLs were noticeably more positive than their level of knowledge or use. They considered them easy to use (item 7), accessible (item 8) and useful in improving their teaching performance (item 9). Furthermore, they recognized their value in the teaching of science (item 10) and their potential for achieving multiple educational objectives (item 11).

Among the disadvantages (item 12), they identified the need for infrastructure, digital competences, the lack of direct handling and the time required for their selection. Nonetheless, they valued their advantages

even more (item 13), particularly with regard to the environment, the possibility of repetition, safety, time savings, interactivity and lower cost.

Items	Mean	Standard Deviation	Variance
7) Degree to which you believe that VLs are easy to use	3.40	1.107	1.225
8) Degree to which you believe that it is easy to find a VL to teach your science course	3.21	1.152	1.327
9) Degree to which you believe that the use of VLs would improve your effectiveness as a science instructor	3.86	1.143	1.307
10) Level of importance you give to the use of VLs in Science teaching	3.84	1.144	1.308
11) Degree to which you believe that the following goals can be reached through the use of VLs:			
a. Promoting active learning	3.77	1.182	1.396
b. Promoting the development of scientific skills	3.78	1.185	1.405
c. Introducing students to the scientific method	3.81	1.191	1.418
d. Familiarizing students with experimentation	3.82	1.166	1.359
e. Experimenting in a risk-free environment	3.81	1.218	1.484
f. Taking advantage of technology tools when infrastructure is lacking to experiment in educational institutions.	3.81	1.203	1.448
g. Promoting the use of Information and Communication Technologies among students	3.90	1.195	1.428
12) Level of importance they give to the following disadvantages of VLs:			
a. Lack of direct handling of laboratory equipment and instruments	3.18	1.255	1.575
b. Requirement for having an adequate technological infrastructure	3.35	1.318	1.736
c. Requirement for a rigorous search and selection process	3.17	1.223	1.495
d. Requirement for digital competences among the instructors that use them	3.31	1.231	1.516
e. Requirement for digital competences among the students that use them	3.31	1.231	1.516
13) Level of importance they give to the following advantages of VLs:			
a. Interactivity	3.76	1.186	1.407
b. Safety of use	3.81	1.166	1.360
c. Possibility of repeating the experiment an unlimited number of times	3.84	1.192	1.420
d. Sustainability, as it does not harm the environment.	3.86	1.204	1.450
e. Lower cost	3.73	1.212	1.470
f. Time savings	3.76	1.182	1.397
14) Degree to which you believe that VLs can replace physical laboratories	3.21	1.083	1.174
15) Degree to which you believe that VLs can expand the possibilities of physical laboratories	3.58	1.106	1.223
16) Degree to which you would be willing to learn more about the use and application of VLs in the teaching of Science	4.07	1.118	1.249
17) Degree of potential you see for LVs in teaching Chemistry	3.86	1.114	1.241
18) Degree of potential you see for LVs in teaching Physics	3.90	1.129	1.274
19) Degree of potential you see for LVs in teaching Biology	3.89	1.147	1.315

Table 4. Descriptive statistics for the items in block 3

They stressed that LVs extend rather than replace physical laboratories (item 14), and that they are useful in Physics, Biology and Chemistry, although with slight differences (item 15). Finally, they showed a high

level of willingness to continue to train in this area (item 16), with this item being the highest rated on the questionnaire.

3.2. Variation of the Results According to the Sociodemographic Characteristics of the Educators

The sociodemographic variables considered were: gender, age, subject taught, highest academic level and type of educational institution. Below are the results of the analysis for the complete questionnaire, which we have called the 'Global' variable, and for each of the blocks of which it consists.

3.2.1. Sociodemographic Factor: Gender

Figure 2 shows the means and standard deviations for the full questionnaire and for each block according to educator gender, along with the results of the Mann-Whitney U test. The analyses indicated that the responses do not vary significantly according to gender, since no significant differences were found ($p < 0.05$) in the global score ($p = 0.231$) or in the Knowledge ($p = 0.622$), Use ($p = 0.074$) or Perception ($p = 0.108$) blocks. Even though the Use block shows a p value close to the threshold of significance (0.074), it still does not reach the conventional level of statistical significance.

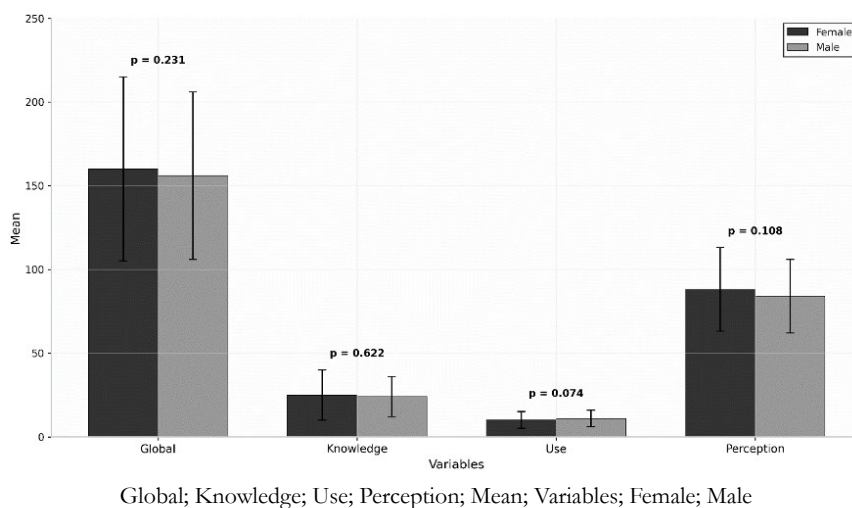


Figure 2. Results of the descriptive statistics and the Mann-Whitney U test for the gender factor (The error bars represent the standard deviation)

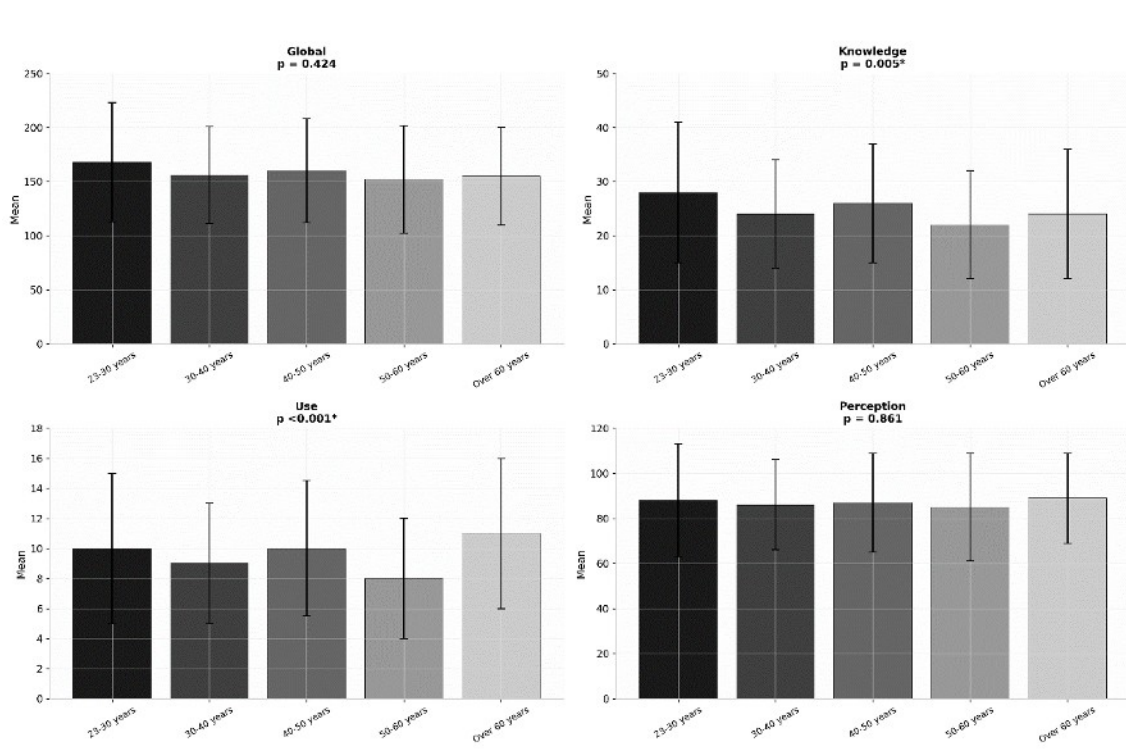
3.2.2. Sociodemographic factor: age

For the analysis of the age factor, a grouping was made of this variable. Figure 3 presents the means and standard deviations of the full questionnaire and for each block, according to the age group of the educators, along with the results of the Kruskal Wallis test. The analyses indicate that there are significant differences according to age in the Knowledge block ($p = 0.005$) and the Use block ($p < 0.001$), while no significant differences were found in the global score ($p = 0.424$) or in the Perception block ($p = 0.861$).

The results of the analysis show that there are significant differences ($p < 0.05$) for blocks 1 and 2, and therefore, both the knowledge and the use of VLs is influenced by the age of the participants.

Table 5 shows, for blocks 1 and 2, the comparisons of pairs corresponding to the age factor, generated by the SPSS v.28 program, only for those variables that show significant differences between the different ranges of the analyzed factor.

In both the knowledge and the use of VL blocks, the differences appear between the 50-60 years of age group and the previous age ranges. Specifically, and as shown in Figure 3, the educators in the 50–60-year age range are the ones who show the worst results in both block 1 and block 2.



Mean; Global; Knowledge; Use; Perception; Descriptive statistics by age group; 23-30 years; 30-40 years; 40-50 years; 50-60 years; Over 60 years. *Significant at a 95% confidence level. The error bars represent the standard deviation

Figure 3. Descriptive statistics and Kruskal-Wallis test for the age factor

Group	Block 1: Knowledge (Bilateral sig.)	Block 2: Use (Bilateral sig.)
(50-60 years of age)-(Over age 60)	0.435	0.027*
(50-60 years of age)-(30-40 years of age)	0.057	0.019*
(50-60 years of age)-(40-50 years of age)	<0.001*	<0.001*
(50-60 years of age)-(23-30 years of age)	0.004*	0.011*
(Over age 60)-(30-40 years of age)	0.964	0.230
(Over age 60)-(40-50 years of age)	0.411	0.848
(Over age 60)-(23-30 years of age)	0.332	0.617
(30-40 years of age)-(40-50 years of age)	0.076	0.023*
(30-40 years of age)-(23-30 years of age)	0.105	0.313
(40-50 years of age)-(23-30 years of age)	0.708	0.582

*Significant at a 95% confidence level

Table 5. Comparison of pairs for the age factor

In general, it can be reasonably stated that age has a decisive influence on the level of knowledge, use and perception of the VLs, as they are relatively emergent technologies. However, in this research the only significant results were for those educators who were 50-60 years of age, who scored lower than the other age groups in the knowledge and use of VLs, but not in their perceptions.

In order to determine the effect size of the differences found for age in blocks 1 and 2 of the questionnaire, eta squared (η^2) was calculated, which is a measure that quantifies the strength of association between the independent variable and the dependent variable by estimating the proportion of variance explained in the dependent variable that can be attributed to the independent variable. The result was 0.040 for block 1 and 0.055 for block 2, which according to López-Martín and Ardura (2023), indicates a small effect size. This indicates to us that the differences found are weak.

3.2.3. Sociodemographic Factor: Subject Taught

Figure 4 presents the means and standard deviations for the full questionnaire and for each block, according to the subject taught by the educators, along with the results of the Kruskal Wallis test. The analyses indicate that there are no significant differences according to subject in any of the variables evaluated: Global score ($p = 0.596$), Knowledge ($p = 0.104$), Use ($p = 0.104$) or Perception ($p = 0.909$). Even though the Knowledge and Use blocks show p values close to the significance threshold (0.104), they do not reach the conventional level of statistical significance ($p < 0.05$). This might be due to the fact that educators that teach experimental sciences in the different subjects receive similar training in the technological aspect.

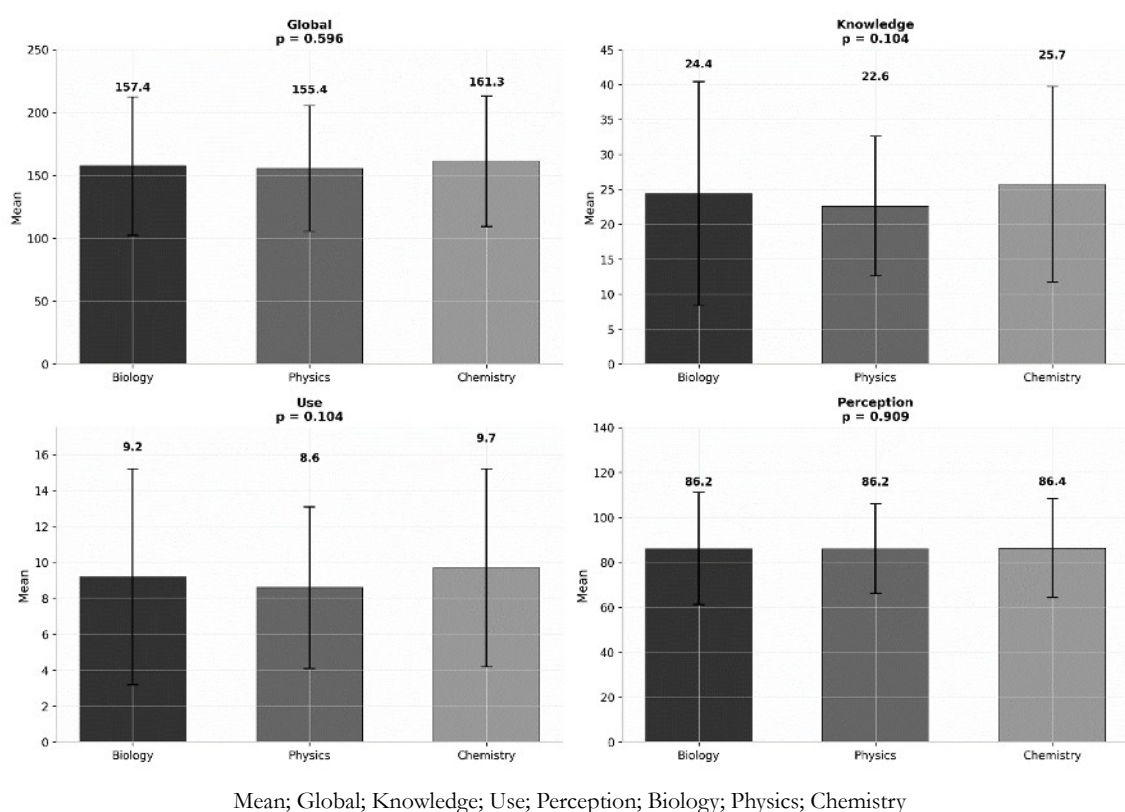
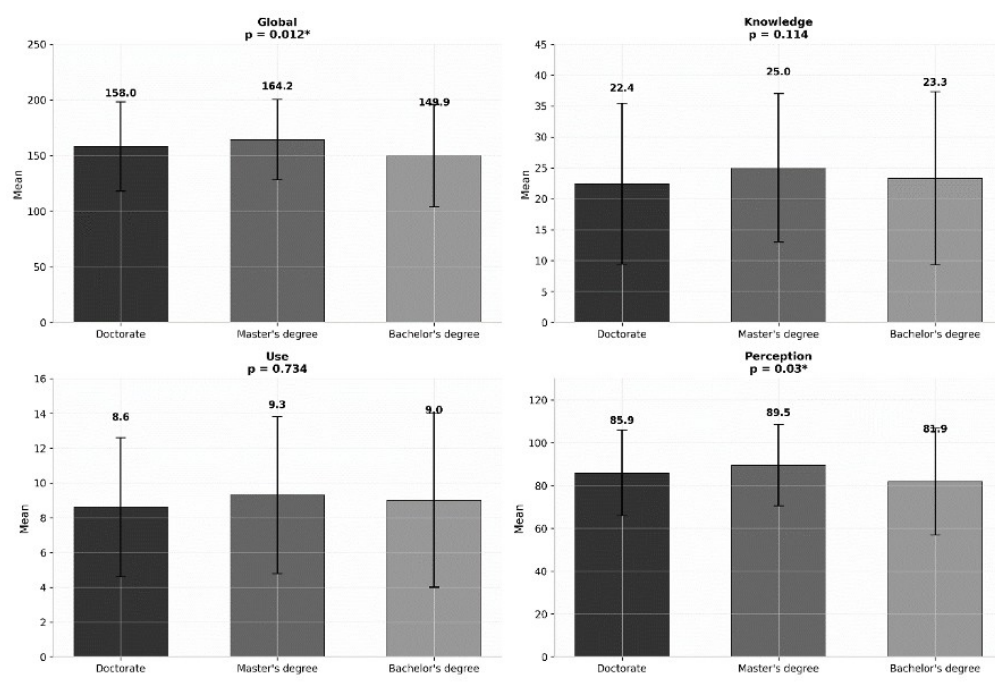


Figure 4. Descriptive statistics and Kruskal-Wallis test for the demographic factor of subject taught (The error bars represent the standard deviation)

3.2.4. Sociodemographic Factor: Maximum Level of Studies

Figure 5 presents the means and the standard deviations for the full questionnaire and for each block according to the level of studies reached by the educators, along with the results of the Kruskal Wallis test. The analyses indicate that there are significant differences according to the level of studies on the Global score ($p = 0.012$) and on the Perception block ($p = 0.030$), while no significant differences were found in the Knowledge ($p = 0.114$) or Use ($p = 0.734$) blocks. In terms of the global score, the educators with a master's degree had the highest mean (mean = 164.15, SD = 35.96), followed by those with a doctorate (mean = 158.00, SD = 33.54) and a bachelor's degree (mean = 149.90, SD = 45.91). In Perception, educators with a master's degree also present the highest mean (mean = 89.52, SD = 19.12), as compared to those with a doctorate (mean = 85.91, SD = 19.81) or a bachelor's degree (mean = 81.88, SD = 24.81).



Mean; Global; Knowledge; Use; Perception; Doctorate; Master's degree; Bachelor's degree
 *Significant at a 95% confidence level. The error bars represent the standard deviation

Figure 5. Descriptive statistics and Kruskal-Wallis test for the factor level of studies reached

Table 6 shows the comparisons by pairs for the Global and Perception variables according to the level of studies (performed using SPSS v28). The results show that educators with a master's degree obtain higher scores than those with bachelor's degrees. The effect size, measured by eta squared (η^2), was 0.029 for both variables, indicating significant differences, but of a weak magnitude.

These results suggest that a master's degree better prepares educators in technological aspects related to VLs. Therefore, knowledge, use and favorable perception of virtual laboratories seem to depend on the level of training, although in the case of doctorates, a gradual progression is not observed, similar to what occurs for those who have earned a master's degree.

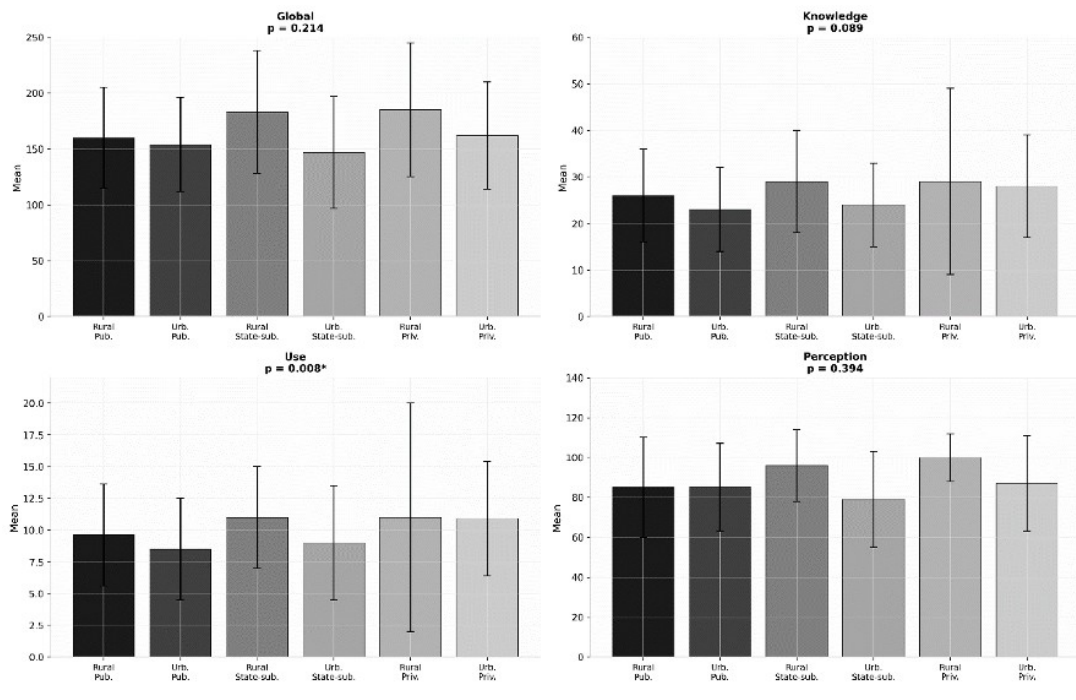
Group	Global	Block 3: Perception
Bachelor's degree-Doctorate	0.653	0.820
Bachelor's degree-Master's degree	0.03*	0.09
Doctorate-Master's degree	0.572	0.501

*Significant at a 95% level of confidence

Table 6. Comparison by pairs for the level of studies reached (bilateral significance)

3.2.5. Sociodemographic Factor: Type of Educational Institution

Figure 6 shows the means and standard deviations for the full questionnaire and each block, according to the type of institution (public, state-subsidized, private) and area (rural, urban), along with the results of the Kruskal Wallis test. The analyses indicate that there are significant differences in the User block ($p = 0.008$), while no significant differences are found in the global score ($p = 0.214$), Knowledge ($p = 0.089$) or Perception ($p = 0.394$). Even though the Knowledge block shows a p value that is close to the significance threshold (0.089), it does not reach the conventional level of statistical significance. In the Use block, it is observed that rural private institutions and rural state-subsidized institutions have the highest means (mean = 11.00), followed by urban private schools (mean = 10.86), while urban public institutions show the lowest mean (mean = 8.49).



Mean; Global; Knowledge; Use; Perception; Type of institution: rural public; Type of institution: urban public; Type of institution: rural state-subsidized; Type of institution: urban state-subsidized; Type of institution: rural private; Type of institution: urban private.
 *Significant at a 95% confidence level. The error bars represent the standard deviation

Figure 6. Descriptive statistics and Kruskal-Wallis test for the type of educational institution factor

The only conclusive result, and at the same time a surprising one, is that the educators in urban public institutions obtain worse results in the use of VLs as compared to both their rural counterparts and those from private institutions, who report more frequent use (Table 7). In both pairs, the eta squared (η^2) value of 0.044 indicates that the differences found are weak.

Group	Block 2: Use (bilateral sig.)
Urban public-Urban state-subsidized	0.602
Urban public-Rural public	0.024
Urban public-Rural private	0.575
Urban public-Urban private	<.001
Urban public-Rural state-subsidized	0.218
Urban state-subsidized-Rural public	0.510
Urban state-subsidized-Rural private	0.750
Urban state-subsidized-Urban private	0.140
Urban state-subsidized-Rural state-subsidized	0.372
Rural public-Rural private	0.965
Rural public-Urban private	0.194
Rural public-Rural state-subsidized	0.532
Rural private-Urban private	0.735
Rural private-Rural state-subsidized	0.700
Urban private-Rural state-subsidized	0.855

Table 7. Pairwise comparison for the type of educational institution factor

Table 8 summarizes the results according to the sociodemographic factors. No significant differences were obtained for gender or subject taught. With regard to age, educators 50-60 years of age show the lowest levels for knowledge and use of VLS. With regard to the level of studies, those who only had earned a bachelor's degree have the worst results on both a global level and in the perception block. In terms of the type of institution, educators from urban public centers show a lower level of use of VLS. However, all these differences show small effect sizes, so their impact is limited.

Factor	Group	Significant variables	Worst result
Gender	Female Male	–	–
Age	23-30 years of age	Block 1: Knowledge	50-60 years of age
	30-40 years of age	Block 2: Use	50-60 years of age
	40-50 years of age		
	50-60 years of age		
	Over age 60		
Subject taught	Biology Physics Chemistry	–	–
Level of studies attained	Doctorate Master's degree Bachelor's degree	Global	Bachelor's degree
		Block 3: Perception	Bachelor's degree
Type of educational institution	Rural public Urban public Rural state-subsidized Urban state-subsidized Rural private Urban private	Block 2: Use	Urban public

Table 8. *Synthesis of the results obtained for the sociodemographic factors*

4. Discussion and Conclusions

The results of this study show that Ecuadorian experimental science educators have a highly favorable perception of virtual laboratories (VL), valuing them as useful, versatile instructional tools that are complementary to physical laboratories, in line with what has been reported by Giroto-Junior et al. (2022). Furthermore, they report a strong willingness to expand their knowledge and educational use, which is promising, given that a positive attitude constitutes a key element for their effective integration in the classroom (Santos & Prudente, 2022).

However, the real use of VLS remains low, at levels between occasional and seldom, which coincides with previous studies (Heintz et al., 2015; Alshaikh, 2022; García-Huamán, 2022; Moawyah & Mahmood, 2022). This low frequency could be due to limited knowledge about VLS and the lack of training in specific educational strategies for their use. As suggested by Moawyah and Mahmood (2022), teacher training and equal access to these technologies are necessary prerequisites for their generalized adoption.

This gap between good intentions and real use constitutes a global phenomenon. Shambare and Jita (2025) found that in rural South African schools, in spite of high scores on the intention to use them (mean = 4.00) and perceived usefulness (mean = 3.90), the effective implementation remains limited by contextual structural barriers, suggesting that the technological acceptance model (TAM) needs to be complemented by external variables that capture the specific characteristics of the educational context.

Educators identify specific training, alignment with the curriculum and the availability of technological infrastructure as key conditions for the use of virtual laboratories. These demands coincide with previous

findings (Špernjak & Šorgo, 2009; De la Rama et al., 2020), which stress the importance of training and access to the resources for effective implementation of ICTs in science education.

On an international level, these barriers are confirmed: the meta-analysis by McGehee (2024) identified the facilitating conditions —institutional support, technical resources and time— as critical factors for transforming intention of use into actual implementation. In contexts in developing countries, these limitations are even more intense. From the framework of TPACK, Shambare and Jita (2024) evidenced that, while educators have technological competences, there are still shortcomings in their instructional integration, which limits the meaningful instructional use of virtual laboratories. As a result, teacher training must go beyond the instrumental domain and must incorporate specific educational strategies.

With regard to sociodemographic factors, no significant differences are observed by gender or subject, although slight variations do occur according to age and educational level. Older educators show less use, while post-graduate training (especially master's degrees) is associated with better results. These findings partially contrast those of Moreno-Mediavilla et al. (2023), who found no significant differences according to personal or training variables, which suggests the influence of context.

In Ecuador, the limitations related to access and connectivity are decisive: a significant proportion of the students lack devices and adequate connection, and a large portion of the teachers do not have stable institutional resources (Guapulema-Ocampo et al., 2024; Espinoza-Delgado et al., 2025). These shortcomings affect the development of digital competences, especially in rural settings (Pegalajar-Palomino & Rodríguez-Torres, 2023). In contrast to this, in Spain, initiatives such as *Escuelas Conectadas* (Connected Schools) (Red.es, n.d.) demonstrate the impact of sustained public policies in narrowing the digital gap. On a regional level, experiences such as those of Uruguay and Chile reinforce this trend, while other countries continue to face structural challenges (Buchbinder, 2021).

Overall, these results fall within what has been termed the “100-year global gap in educational standards” (Brookings Institution, 2015), highlighting how inequalities in technological infrastructure continue to shape educational opportunities on a global scale.

The comparative evidence suggests that the gap between intention and the behavior observed in the Ecuadorian context does not constitute an isolated phenomenon, rather it follows systematic patterns in countries with similar structural limitations. The study by Liu et al. (2019) specifically examined this gap in foreign language teachers in China, finding the intention to use technology was significantly correlated to teacher-centered uses, but not to student-centered uses, thus revealing that positive intentions do not necessarily lead to profound educational transformations. The authors identified that technological-pedagogical knowledge of the content (TPACK), the facilitating conditions and the institutional culture act as critical mediating factors between intention and effective implementation. This finding has direct implications for the design of teacher training programs in Ecuador, suggesting that they must explicitly incorporate the development of TPACK and not limit themselves to technical skills related to platform management.

One especially relevant finding is that teachers in urban public institutions report less use of VLS than their peers in rural areas and in private centers. One plausible explanation could be the larger group/class sizes in the urban contexts, which complicate the implementation of these tools. However, this result needs to be corroborated by additional research.

The results obtained provide valuable information for the design of teacher training programs focused on the educational use of VLS. They provide a clear diagnosis of the level of knowledge, use and perception of these tools, which will allow us to adapt this training to the real needs of educators. This training must be focused on developing digital competences, the design of effective educational strategies and the integration of VLS in the curriculum.

From a theoretical perspective, the findings contribute to expanding the Technology Acceptance Model (TAM), by showing that in the context of the Southern Hemisphere, the relationship between intention and use is mediated by structural and institutional factors, as well as by the level TPACK development by educators.

As for future lines of research, it is recommended to delve deeper into the design of contextualized training programs, to explore strategies to adapt VLS to the curriculum contents and to ensure access to adequate technological infrastructure. Likewise, it would be important to continue to analyze the factors that influence their effective adoption, in order to maximize the impact of these tools on the teaching and learning of the experimental sciences.

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The authors declare that they have no potential conflicts of interest with regard to the research, authorship and/or publication of this article.

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Authors' contributions

Gabriela Campos-Mera: conceptualization, data processing, formal analysis, research

Alicia Benarroch-Benarroch: revision, acquisition of funds.

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Data availability

Data available upon request.

Use of Artificial Intelligence

The authors declare that the content of the article has not been developed using Artificial Intelligence.

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