Virtual Simulators in The Teaching-Learning of Chemistry and Physics: A Systematic Review of The Literature

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Abstracts: The objective of this study was to describe quantitative metrics related to publications on the advantages offered by virtual simulators for the teaching-learning of students in the subjects of Physics and Chemistry, in different databases such as Ebsco, Dialnet, Scielo, DOAJ, including the time period filter. from 2019 to 2023. In this sense, the search was carried out by consulting the words "Virtual simulators", "Virtual reality", "Exact sciences", "Chemistry", "Physics", in the aforementioned databases. Then, the studies were filtered according to the inclusion criteria, which are open access documents and the subject in the database itself, for subsequent review of the literature. At the end of the review, the last filter was performed by exclusion criteria, leaving 9 studies as a final result. It was evidenced that in 2022 the largest number of publications was made, with a total of 4 and also the highest peak of scientific production. Likewise, it was recorded that scientific research on the subject is also carried out in Peru, but it is necessary to deepen it; However, this number of publications shows a scarce scientific production in Latin America. On the other hand, the results of the most frequent keywords in the studies carried out on this topic were chemistry and learning. Finally, it is concluded that there is a shortage of studies that relate both physics and chemistry. Although there are studies that show us an individualized analysis for each variable.

Keywords: Virtual Simulators, Teaching-Learning, Physics, Chemistry.

1. INTRODUCTION

The rapid advance of technology, the abrupt change generated by the presence of Covid-19 in the social dynamics, and therefore the innumerable changes in the traditional education systems, brought about the inclusion of technological educational tools [1]. The change arose at first from the government, and subsequently began to implement policies and measures for the care of people, in which the educational system changed to a virtual modality; with the main objective of safeguarding the integrity of students and teachers, avoiding the agglomeration of people in closed places; at the same time they sought to continue providing the service, preventing children and young people from delaying their learning [2].

Virtuality represented a challenge for all, which allowed the acceleration of the development of technological competencies for both teachers and students. In this context, the integration of ICT into the renewed teaching-learning process represented a challenge for teachers, since they are useful for teaching practice, but also "play a leading role in providing continuity to the educational process" [3].

The transformation of the educational system reached the exact sciences such as chemistry and physics, being these subjects considered as difficult for the average student [4], [5]. Generally, they require a specialized physical space to study both require specialized equipment, which we usually locate in laboratories, but the recent introduction of ICT to the educational system has allowed the use of online simulators for the teaching-learning process [6].

Simulators are digital tools that allow replicating the behavior of objects and/or materials, allowing a safe environment for the manipulation of students [6]. Students who are generally part of the technological transformation, since long before the appearance of Covid-19, and pioneers in the distance education modality, have high levels of satisfaction with the use of technology in the teaching-learning process; since it represents

several benefits such as the understanding of the behavior of the materials studied, and acquisition of skills in the subjects of study [7]. In fact, the main advantage in the educational context offered by simulators is "the interactive practice that students and teachers can perform between the experimental and the real" [8].

Teaching and learning platforms for physics only include Fisquiweb, while the following can be useful for both physics and chemistry, such as: Phet Interactive Simulations, Educaplus, Virtual Amrita Labs and the Virtual Laboratory Blog, by Salvador Hurtado Fernández [9].

In general, the simulators include physics topics such as: kinematics; dynamics; friction; energy; waves; and chemistry topics such as: thermoelectricity, quantum phenomena, light and radiation, electricity, magnets and circuits; general chemistry; quantum chemistry circuits, among others; which are explained interactively through graphics [9]. The selected simulators are operated with mouse and keyboard controls only so that they can be used on general-purpose digital devices, such as computers, laptops, tablets or smartphones, and do not require any special devices. [10].

This wave of the 21st century, which includes technological applications to the teaching-learning process, seeks to replicate the experiences that could be performed in a laboratory in person [9], on the other hand, achieves a high level of commitment from the students, getting involved and taking charge of their own learning process [10].

Among the simulators, Phet Interactive Simulations stands out due to the facilities it provides, such as access without an Internet connection once downloaded, and its use in Spanish [11]. The ecosystem of this simulator allows obtaining maximum results, as long as it comes from careful preparation; and its importance lies in the simulation of real-life phenomena and the underlying knowledge [12]. For all the above mentioned, the execution of a systematic review of the literature is proposed with the aim of answering the following question What advantages do virtual simulators provide for the teaching-learning of students of Physics and Chemistry subjects?

Therefore, it is intended to systematize the literature that exists in various databases in order to answer the research question regarding virtual simulators in the teaching-learning of chemistry and physics. The general objective of the research is to analyze the literature found in EBSCO, Dialnet, DOAJ and Scielo on virtual simulators in the subjects of chemistry and physics in the last 5 years. The specific objectives are: to identify the annual scientific production; the production of the countries; the language of publication of the studies; the frequency of the authors' keywords; which are the databases with the highest frequency; to show the variety of sources included in the systematic review; with respect to the content, to collect the information of the researches according to the places of publication, words; dimensions; instruments used; the approach of the researches; strategy of the researches and their conclusions.

2. **METHODOLOGY**

The present research has been carried out with a quantitative approach for the elaboration of a systematic review of the literature on virtual simulators in the subject of chemistry. For this reason, systematic review is defined as the process of planning, preparing and publishing quality research that is a critical and reproducible summary or synthesis of published studies related to the topic of study, which supports the understanding of the subject to improve the answers to scientific questions. Thus, systematizing the literature provides the first step for researchers to develop recommendations and identify strengths and weaknesses, as well as to update previous knowledge in order to make better decisions [13].

The execution of the article used the PRISMA methodology (Preferred Reporting Items for Systematic reviews and Meta-Analyses), this is a scope of strict guidelines for scientific publications in order to improve the quality and integrity of documents in systematic reviews and meta-analysis. Moreover, the methodology follows a series of sequential steps that should be reproducible without errors, taking into account the different stages of the process from the identification of records or bibliographic sources (through the practice of electronic search in scientific databases), the full-text studies (articles that must contain the full text in PDF for proper understanding and

eligibility), to the fulfillment of the eligibility criteria of the review so that they can fit in one or more future publications [14].

It should be noted that PRISMA has improved and included new concepts and execution methods during the last few years, which has generated great results, the methodology is useful for planning, implementation and ensures that all the information in the literature is captured [15], [16].

During the first stage of research execution, the following points of the PRISMA methodology were used: sources of information, eligibility criteria, strategy for the search of studies and method of information selection. The sources of information taken into account for the identification of the literature were databases such as: Scielo, EBSCO, Dialnet, Doaj and Scopus. For this, within the fields "Article, title, abstract and keywords" the following words were used: "Virtual simulators", "Virtual reality", "Exact sciences", "Chemistry", "Physics", establishing a time period of the last 5 years (2019-2023). However, due to the complication of mixing study variables to find studies, in some cases we searched for individual variables, and in various contexts. In the initial search, a total of 170 studies were found, of which, after passing the initial phase, passed strict guidelines for inclusion and exclusion of the literature, which are detailed in Table 1. Finally, 9 studies were included for the systematic review.

Table 1. Criteria applied for study selection.

C1	The title or abstract contains one or all of the study variables.
C2	The keywords are associated with the study variables.
C3	The publication date corresponds to the period established for the review.
C4	The language of the student corresponds to the languages accepted for review.
C5	The country of the research corresponds to the spatial delimitation of the review.
C6	The study is available in its full version (open access).
C7	The study addresses educational research issues..
C8	The study makes use of the simulator or virtual reality in the educational context.
C9	The study is developed in material of exact sciences (Chemistry and Physics).

For the next stage of results, the selected records were divided into 2 segments: a bibliometric analysis and a content analysis of the literature (scientific evidence).

3. RESULTS

During the result phase, the data obtained with respect to virtual simulators in the teaching-learning of chemistry and physics are described and divided into bibliometric results and content results.

3.1. Bibliometric Results

Figure 1 shows the annual scientific production, where it can be seen that, of all the studies consulted, only articles were registered between 2020-2022, with 2022 being the year with the highest production index with (n=4) published studies. During 2020, only three studies were registered, ending with the year 2021, which was the lowest index with (n=2) published articles.

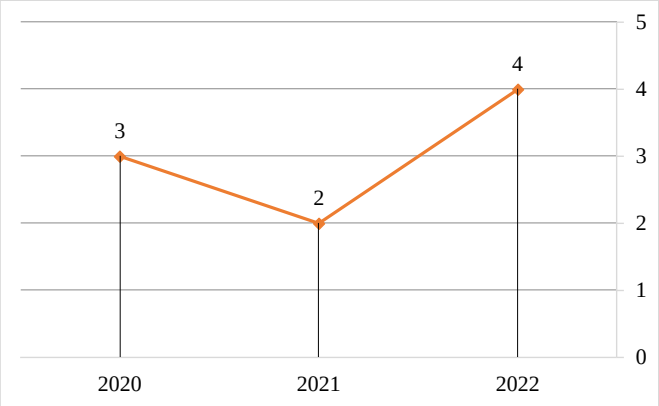

Figure 1. Articles included in the systematic review according to publication year.

Figure 2 shows the countries with the highest scientific production. Ecuador was identified leading the publications with (n=3) studies and Colombia with (n=2) published articles. Finally, there was at least one entry from the following countries: Angola, Mexico, Peru and Venezuela.

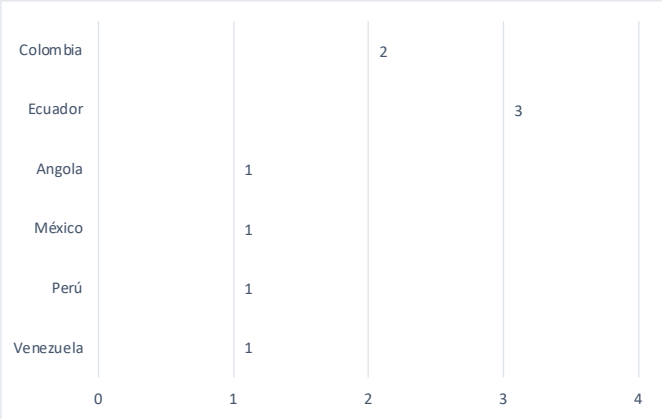

Figure 2. Articles included in the systematic review by Country or Region.

According to the language of the studies published, studies in English and Spanish were included. The majority of the studies are in Spanish represented by 89% (n=8) published studies. The smallest number of studies is in English which is represented by 11% which is (n=1) published study, as shown in Figure 3.

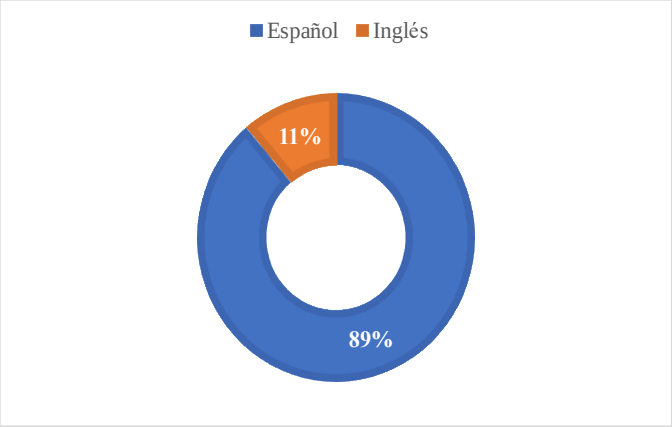

Figure 3. Articles included in the systematic review according to language of publication.

During the identification and analysis of studies, it was important to quantify the frequency of keywords and shows a general frequency overview of all keywords. In this sense, Fig. 4 shows that the authors' keyword with the highest frequency is "Chemistry" with a (n=4). In addition, the second most frequent keyword is: "Learning" with a frequency of (n=3).

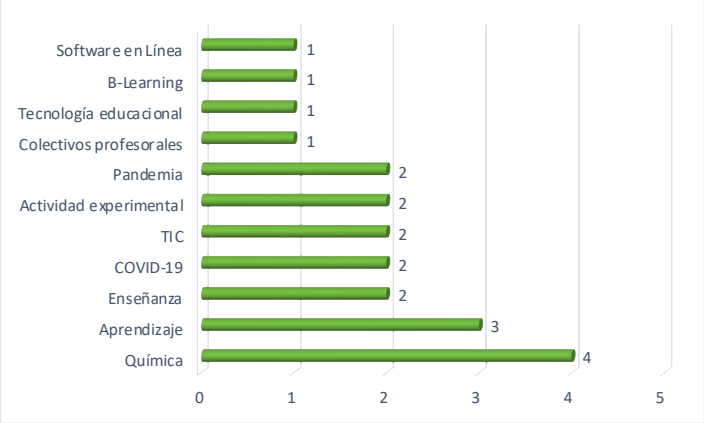

Figure 4. Articles included in the systematic review according to key words

The period of identification of records included the search for information in different databases. The databases with the highest frequency of publication were EBSO host and Dialnet with (n=3) studies each. On the other hand, DOAJ (Directory of Open Access Journals) had a frequency of (n=2) studies. Finally, the Brazilian database Scielo only had a frequency of (n=1) indexed article.

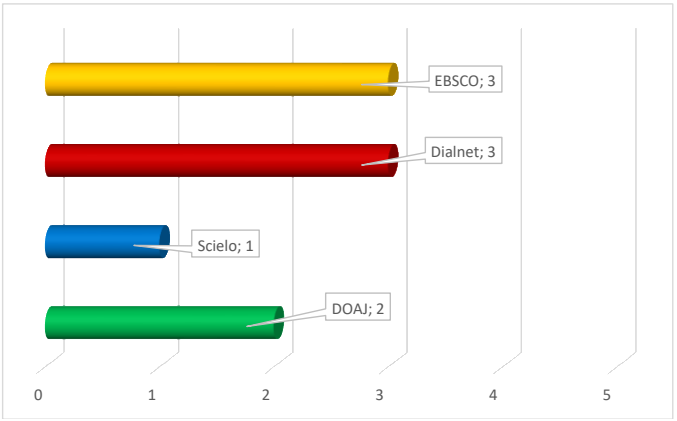

Figure 5. Bar chart showing the variety of databases consulted.

The period of identification of records included the search for information in different databases. The databases with the highest frequency of publication were EBSO host and Dialnet with (n=3) studies each. On the other hand, DOAJ (Directory of Open Access Journals) had a frequency of (n=2) studies. Finally, the Brazilian database Scielo only had a frequency of (n=1) indexed article.

Information sources (scientific journals) are very important in scientific research. For this reason, Table 2 shows the variety of sources included in the systematic review on virtual simulators in the teaching-learning of chemistry and physics.

Table 2. Sources included in the systematic review.

Source
CHAKIÑAN, Social Sciences and Humanities Journal
IKASTORRATZA. didactics e-journal
Cognosis Magazine
Journal of Educational Sciences, Teaching, Research and Information Technologies: CEDOTIC
Research Journal Apuntes Universitarios
Dilemas Contemporáneos: Education, Politics and Values Journal
University Teaching Magazine
Inter-American Journal of Research in Education and Pedagogy RIIEP
Revista Relep - Educación y Pedagogía en Latinoamérica

3.2. Content Results

Table 3 and 4 show the results through the scientific evidence collected from the 9 studies included in the systematic review.

Table 3. Evidence collected on virtual simulators in chemistry and physics teaching-learning showing: author/year, country of correspondence author, keywords and dimensions

N°	Author/ Year	Title	Country	Key words	Dimensions
1	(Urquizo et al., 2022) [11]	Experimental activities using virtual simulators to learn chemistry during COVID-19 pandemic [Actividades experimentales utilizando simuladores virtuales para el aprendizaje de química en tiempos de pandemia por COVID-19].	Ecuador	Experimental activity, covid-19, chemistry, simulator, virtual laboratory.	Methodology change, teaching-learning, feedback, motivation, experiential activity, academic performance.
2	(Largo et al., 2022) [17]	ICT-mediated chemistry education: a paradigm shift in an education in emergence	Colombia	Teaching, evaluation, educational innovation, chemistry, pandemic, ICT.	Student perception, data collection, ICT use, student motivation.
3	(Góngora y Santana, 2021) [18]	Theoretical and practical strengthening of the teaching of chemistry through the application of virtual simulators to students in the second year of high school at the Uruguay Technical Educational Unit in the city of Portoviejo in the province of Manabi.	Ecuador	Virtual simulator, teaching, learning, chemistry.	Innovation, skills, skills needed, data collection, training.
4	(Carrión et al., 2022) [19]	PhET virtual simulator as a methodological strategy for learning chemistry.	Ecuador	Educational technology, learning, educational strategies, school laboratory, pedagogical innovation.	Methodological strategy, pedagogical use, chemistry learning in students, data collection, optimizing learning.
5	(Tovar et al., 2020) [20]	The structuring of a tool for teaching high school chemistry (EduQuim) using the Moodle platform and the opinion of students and teachers.	Venezuela	Chemistry Education, B-Learning, B-Learning, ICT, Educational Videos.	Positive attitudes and perceptions, Acquire and integrate new knowledge, Organize information, Extend and refine knowledge, Develop habits of mind to think critically.
6	(Martínez et al., 2022) [21]	Remote attendance model for Physics I, II and III	Colombia	Learning strategy, audiovisual media, teacher collectives, teamwork, team teaching.	Use of resources, synchronous and asynchronous work, virtual materials, low cost available in students' homes.

7	(Flores et al., 2022) [22]	University student perspective on the use of virtual laboratories in response to the challenges of pandemic 2020.	Mexico	Learning, students, virtual labs, teachers, pa	Deficient learning by doing, Learning environments, Digital literacy, Student population.
8	(Delgado et al., 2021) [23]	PhET virtual simulator for learning chemistry in COVID-19 time	Angola	PhET simulator, experimental problem-solving activity, chemical bonding, COVID-19.	Radical change, face-to-face education to emergency remote teaching, didactic sequence, learning theory, improved understanding.
9	(Estela et al., 2022) [24]	Online software for conceptual learning of physical and geometrical optics	Peru	8Optics, online software, conceptual learning, simulation.	Level of learning gain, Data collection, student perception, average effectiveness.

Table 4. Scientific evidence on virtual simulators in the teaching-learning of chemistry and physics, identifying instrument, approach, strategies and conclusions.

N°	Instrument	Focus	Strategies	Conclusions
1	Simulador PhET (Physics Education Technology) Laboratorios virtuales: Crocodile Chemistry 605 Yenka	Quantitative	The construction of the didactic sequence through the use of simulators facilitated the understanding of the teaching-learning processes, following the methodology of the three pedagogical moments. These simulators are very attractive and present real-life cases to demonstrate the applicability of the contents discussed. In addition, the results of the simulations allow observation of phenomena at micro and macro levels during experimentation, allowing instant feedback at both group and individual levels, as needed.	The second, third and fifth semester students showed interest in the simulators and virtual laboratories PhET, Crocodile Chemistry605 and Yenka, since they consider them versatile tools that facilitate the feedback of the contents both synchronously and asynchronously. In addition, the use of simulators such as PhET and virtual laboratories, such as Crocodile Chemistry605 and Yenka, has facilitated the understanding of the teaching-learning processes, incorporating the three pedagogical moments: initial problematization, organization of knowledge and application of knowledge. The simulators have provided feedback and motivation during the development of each experimental activity.
2	ICT tools Virtual Labs Simulators	Qualitative	To determine students' perception of the subject of chemistry, the use of information and communication technologies (ICT) in teaching, as well as the use of virtual laboratories and simulators to improve laboratory practices. The objective was to evaluate how students adapted to the use of digital platforms to learn chemistry and carry out virtual practices.	It was concluded that the use of ICT tools in educational processes boosted students' willingness and motivation to learn chemistry as an experimental science. it is essential to recognize that progress in educational processes, through the use of information and communication technologies (ICT) or virtual platforms, encourages students to develop autonomy, independence and responsibility. It was observed how students valued and considered important the use of virtual platforms and simulators for chemistry classes and laboratory practices.
3	Virtual Simulators VLabQ and Qgenerator Virtual Chemistry Laboratory	Mixed (Quantitative - Qualitative)	It allows the generation of customized practices, providing greater value, since teachers can adapt it to any type of practice they wish to carry out in class, especially when it involves the use of hazardous components and solutions. The virtual chemistry laboratory allows students to simulate experiments easily and safely, with the presentation of results in graphical form.	It has been found that the lack of frequent experimental practices by teachers leads to an incomplete understanding of the topics by students. Likewise, this generates ignorance about the structure of a laboratory. Chemistry teachers rarely carry out experiments due to factors such as shortage of materials and reagents, lack of organization in laboratory assignment, and the risk of loss of objects during student participation.
4	PhET virtual simulator	Quantitative	The application of the PhET virtual simulator in education is proposed through a pedagogical approach that includes several steps, from free access to the software to linking scientific content with the simulation. The goal is to arouse interest and foster scientific thinking in students. When used as an interactive educational tool, the PhET virtual simulator has a significant impact in several aspects. First, it is easily accessible	The results of the research show that 48.9% of the respondents are in favor of using the virtual simulator in the chemistry teaching process. They consider that this tool facilitates learning and overcomes the limitations of traditional classes that do not include experimental laboratories and lack motivation to learn the subject. They also agree that teachers should incorporate virtual simulators as a new methodological strategy in the classroom. It is

			and free to register. In addition, it offers a wide range of simulations ranging from simple to complex, which benefits both teachers and students.	essential that teachers appropriate and use these new strategies to favor cognitive development, interaction among students and their willingness to learn and improve their learning through the advantages offered by the virtual simulation world.
5	EduQuim Moodle Platform	Quantitative	The educational platform has users such as administrators, students, teachers and research groups, each with different functions. It stores database tables for students, institutions, courses, among others. Used to investigate and improve the learning of chemistry in high school students, if students are enthusiastic about learning the concepts of chemistry through this platform, it could improve the teaching of the subject and increase the academic performance of high school students.	The implementation of EduQuim in Moodle was very convenient, adequate and relatively simple thanks to the advantages it offers, such as the inclusion of video-classes, mini-games, interactive exercises, a molecular builder to visualize molecules in 2D and 3D, the possibility of cooperative learning through chats and forums, and the evaluation through the Knowledge Challenge. EduQuim is an educational research tool whose components can be modified and optimized to improve understanding, critical reflection and learning of chemistry concepts in high school students.
6	WeekApp Plataforma Moodle	Quantitative	Laboratory practices were implemented using virtual or low-cost materials, accessible from students' homes. To manage and visualize the resources in the Moodle classrooms, the WeekApp application was developed. These resources include videos, readings of interest, presentations, self-assessments, simulators and other additional materials, organized by ExperTIC. The WeekApp was used to facilitate access to these resources on the Moodle platform, taking into account the estimated weekly independent work time of the students.	El 85,7% de los estudiantes de Física I, el 96,3% de Física II y el 86,8% de Física III informaron que sus profesores utilizan los recursos creados en mayor o menor medida, y el 79,6% se mostró muy satisfecho con dichos recursos. Este ejercicio logró cubrir satisfactoriamente todas las etapas del ciclo de vida de creación, gestión y curaduría de recursos y contenidos, proporcionando valiosas lecciones sobre la colaboración entre docentes y el desarrollo de estrategias de aprendizaje utilizando tecnologías de la información y la comunicación (TIC).
7	Virtual Simulators Virtual Laboratories	Mixed (Quantitative - Qualitative)	For practical subjects, such as laboratories, the use of virtual simulators was used, which postponed the acquisition of practical skills in the handling of materials, equipment and reagents by students. In addition, each degree program seeks to obtain national and international quality certifications, which implies that practical knowledge, generally acquired in laboratories, is crucial for its evaluation, since the theoretical knowledge obtained is applied in these laboratories.	Indicates how virtual laboratories become a means to create meaningful learning environments during the pandemic for students of practical or theoretical-practical subjects. The implementation of virtual laboratories has been of great help to students who studied practical subjects during this period, since it allowed them to carry out practical procedures online and strengthen their theoretical knowledge. These virtual laboratories facilitate the development of laboratory practices, reduce costs and the risk of accidents. They are an excellent learning option, since students can repeat practices as many times as necessary without having to invest in laboratory equipment and reagents.
8	Simuladores PhET (Physics Education Technology) - Química	Qualitative	The didactic sequence based on Ausubel's theory of meaningful learning consists of three pedagogical moments, where the PhET simulator for Chemistry is used. This sequence allows the identification of chemical bonds through a problematizing experimental activity, which enhances cognitive development and critical and reflective understanding of scientific knowledge by students, improving their understanding and learning results..	It is recognized that teaching is not a simple process, since finding appropriate methodologies for any teaching modality takes time and depends largely on the individual dedication of each teacher to specialize and meet the needs of both parties. The methodology of the Three Pedagogical Moments is presented as a possible alternative to carry out problematizing experimental activities in Chemistry, in a way that is closer to the students' reality and promotes a critical and reflective appropriation of scientific knowledge.
9	Online Simulators Online software	Quantitative	It allows reducing the generation gap, provided that teachers show openness towards new technologies and promote interaction with students. In this way, the development of autonomous and	The use of online simulators as a teaching-learning strategy in virtual environments has been shown to significantly improve the conceptual learning of geometrical optics in university students. The results show a

			collaborative work in the educational process is encouraged. The objective of the online laboratory is to virtually replicate all controlled physical conditions, which makes it more efficient in the reproduction of phenomena and in the performance of mathematical calculations compared to a traditional laboratory.	favorable evolution in the students' physical conceptions and their ability to extrapolate this knowledge to everyday situations, which highlights the effectiveness of these interventions in class.

CONCLUSION AND DISCUSSION

The Covid-19 pandemic has led to a significant change in the perception of virtual and distance education programs, and as a result, pedagogical practices have had to be transformed from a mostly face-to-face or traditional approach to a technology-mediated teaching model. This has generated the need to implement changes in the teaching and learning processes. It should be noted that the teaching of chemistry through virtual platforms offers students the opportunity to develop additional competencies through different pedagogical strategies and mediations (largo and tovar). This not only strengthens the concepts of the subject, but also facilitates access to laboratory practices, which are fundamental for training in the natural sciences. The findings indicate that the educational processes supported by ICT tools had a positive impact on the students' willingness and motivation towards learning Physics, opting to perform laboratory practices using virtual or low-cost materials that were available in the students' homes [21].

The use of PhET simulators and virtual laboratories provided feedback and motivation during experimental activities, generating interest in students as they consider them versatile tools that allow synchronous and asynchronous feedback, according to research [11]. In addition, the PhET virtual simulator and other online simulators facilitate learning and overcome the limitations of traditional classes that lack experimental laboratories and motivation to learn the subject [19], [24].

However, there is a specific group of students in which they are unfamiliar with the structure of a laboratory, due to the lack of frequent experimental practices by the teachers, resulting in incomplete understanding of the topics by the students [18]. The act of teaching is not a simple task, since finding suitable methods for any type of teaching requires time and depends largely on the individual dedication of each teacher to specialize and meet the needs of both parties involved [23]. These simulators are of great utility and contribute to the teaching-learning process effectively, rarely perform experiments due to various reasons, including shortage of materials and reagents, lack of organization in laboratory assignment, and the risk of loss of objects during student participation. Also, a lack of practical mastery and knowledge in the use of virtual simulators by both students and teachers was detected, the rapidly changing educational environment has generated deficiencies in the acquisition of skills and knowledge using these virtual laboratories [22]. It is important to recognize that virtual technologies may change over time, so it is necessary to continue updating and innovating in the use of ICT to improve the educational experience.

It is concluded that virtual simulators in Physics and Chemistry offer a valuable tool to enrich the educational process, facilitating the understanding of complex concepts, encouraging active learning and providing a safe and accessible environment for experimentation and exploration of scientific phenomena.

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