Publicaciones. Facultad de Educación y Humanidades del Campus de Melilla
Depósito legal: GR-94-2001 · eISSN: 2530-9269 · pISSN: 1577-4147
Editor: Facultad de Ciencias de la Educación y del Deporte de Melilla (Universidad de Granada)

Virtual Electromagnetism Laboratory as a didactic strategy using situated learning approach in engineering

Laboratorio Virtual de Electromagnetismo como estrategia didáctica utilizando el enfoque de aprendizaje situado en ingeniería

虚拟电磁实验室在工程学中的教学策略: 使用情境学习方法

Виртуальная лаборатория электромагнетизма как дидактическая стратегия, использующая подход ситуационного обучения в инженерном деле

Nereyda Castro-Gutiérrez
Veracruzana Univesity
nercastro@uv.mx
https://orcid.org/000-0002-3941-795X

Jesús Alberto Flores-Cruz
National Polytechnic Institute
jafloresc@ipn.mx
https://orcid.org/0000-0001-7816-4134

Fermín Acosta Magallanes
National Polytechnic Institute
facostam@ipn.mx
https://orcid.org/0000-0003-1471-5376

Dates · Fechas

Recibido: 2022-07-19
Aceptado: 2022-09-22
Publicado: 2023-01-01

How to Cite this Paper · Cómo citar este trabajo

Castro-Gutiérrez, N., Flores-Cruz, J. A., Acosta Magallanes, F. (2023). Virtual Electromagnetism Laboratory as a didactic strategy using situated learning approach in engineering. *Publicaciones, 53*(2), 275–292. https://doi.org/10.30827/publicaciones.v53i2.26827

Abstract

Virtual laboratories (VL) have had a special interest in recent years in which immersive education is attractive to students and complements the teaching and learning processes in institutions of diverse educational levels. Although there are several types of virtual laboratories used at various educational levels, there are important challenges for their design as an ad-hoc didactic strategy. One of the main difficulties in the application of educational technology is having virtual educational environments especially dedicated to the areas of engineering, which not only present interactive practical sessions where animations are manipulated, but also encourage the metacognitive analysis of the students; in order to build an autonomous and reflective learning through educational approaches that accompany educational innovation through new technologies. This article presents the design and implementation of a Virtual Laboratory of Electromagnetism (VLE) as a didactic strategy under the situated learning approach, remotely applied to university engineering students through portable versions of the didactic tool designed with Unity® in a public university of Mexico. This research describes the context of the case study, the methodology to identify the criteria under the approach of the situated learning educational model suggested for the development of the virtual environment, the characteristics of the design through animation software, and the educational intervention implemented at the university education level. Finally, an analysis of the results obtained after the application of the laboratory is carried out by studying the perception of the university community through exit surveys.

Keywords: Virtual Laboratory, electromagnetism, engineering, immersive education, situated learning, educational technology, virtual reality.

Resumen

Los laboratorios virtuales (LV) han tenido un especial interés en los últimos años en que la educación inmersiva resulta atractiva para los estudiantes y complementa los procesos de enseñanza y aprendizaje en las instituciones de diversos niveles educativos. Aunque existen varios tipos de laboratorios virtuales utilizados en diversos niveles educativos, existen importantes retos para el diseño de estos como estrategia didáctica ad-hoc. Una de las principales dificultades en la aplicación de tecnología educativa es contar con entornos educativos virtuales especialmente dedicados a las áreas de ingeniería, que no sólo presenten prácticas interactivas donde se manipulen las animaciones, sino que fomenten el análisis metacognitivo de los estudiantes; para así construir un aprendizaje autónomo y reflexivo a través de enfoques educativos que acompañen la innovación educativa a través de las nuevas tecnologías. Este artículo presenta el diseño e implementación de un Laboratorio Virtual de Electromagnetismo (LVE) como estrategia didáctica bajo el enfoque de aprendizaje situado, aplicado a estudiantes universitarios de ingeniería de manera remota a través de versiones portátiles de la herramienta didáctica diseñada con Unity® en una universidad pública de México. En esta investigación se describe el contexto del caso de estudio, la metodología para identificar los criterios bajo el enfoque del modelo educativo de aprendizaje situado sugerido para el desarrollo del entorno virtual, las características del diseño a través del software de animación y la intervención educativa implementada en el nivel de educación superior. Finalmente, se realiza un análisis de los resultados obtenidos después de la aplicación del laboratorio mediante el estudio de la percepción de la comunidad universitaria a través de encuestas de salida.

Palabras clave: laboratorio virtual, electromagnetismo, ingeniería, educación inmersiva, aprendizaje situado, tecnologia educacional, Realidad virtual.

Аннотация

Виртуальные лаборатории вызывают особый интерес в последние годы, поскольку иммерсивное образование привлекательно для студентов и дополняет процессы преподавания и обучения в учебных заведениях на различных уровнях образования. Хотя существует несколько типов виртуальных лабораторий, используемых на различных уровнях образования, существуют значительные трудности при их разработке в качестве специальной дидактической стратегии. Одной из основных трудностей в применении образовательных технологий является создание виртуальной образовательной среды, специально предназначенной для инженерных областей, которая не только представляет интерактивные практики, где манипулируют анимацией, но и поощряет метакогнитивный анализ студентов; для того, чтобы построить автономное и рефлексивное обучение с помощью образовательных подходов, которые сопровождают образовательные инновации с помощью новых технологий. В данной статье представлена разработка и внедрение виртуальной лаборатории электромагнетизма в качестве дидактической стратегии в рамках метода обучения на месте, применяемого к студентам инженерных специальностей университетов дистанционно с помощью портативных версий дидактического инструмента, разработанного с помощью Unity® в государственном университете Мексики. В данном исследовании описывается контекст ситуационного исследования, методология определения критериев в рамках образовательной модели обучения на месте, предложенной для разработки виртуальной среды, характеристики дизайна с помощью анимационного программного обеспечения и образовательное вмешательство, реализованное на уровне высшего образования. Наконец, проводится анализ результатов, полученных после применения лаборатории, путем изучения восприятия университетского сообщества с помощью опросов на выходе.

Ключевые слова: Виртуальная лаборатория; электромагнетизм; инженерия; иммерсивное образование; ситуационное обучение; образовательные технологии; виртуальная реальность.

摘要

近年来，虚拟实验室特别引人注目，因其沉浸式教育对学生具有吸引力，并补充了不同教育水平机构的教学和学习过程。尽管在不同的教育水平上可以使用不同类型的虚拟实验室，但在将它们设计为临时教学策略方面仍存在重大挑战。教育技术应用的主要困难之一是拥有专门针对工程领域的虚拟教育环境，不仅提供动画操作的交互实践，还鼓励学生进行元认知分析；通过新技术伴随教育创新的教育方法来建立自主和反思性学习。本文介绍了虚拟电磁实验室的设计和实施，作为情境学习方法下的一种教学策略，通过墨西哥公立大学使用 Unity® 设计的教学工具的便携式版本远程应用于大学工程专业的学生。本研究描述了案例研究的背景、在情境学习教育模型方法下确定标准的方法，为在高等教育层面的虚拟环境的发展提出了建议，通过动画软件设计的特征以及实施的教育干预。最后，通过研究末问卷研究大学社区对其感知，对实验室申请后获得的结果进行分析。

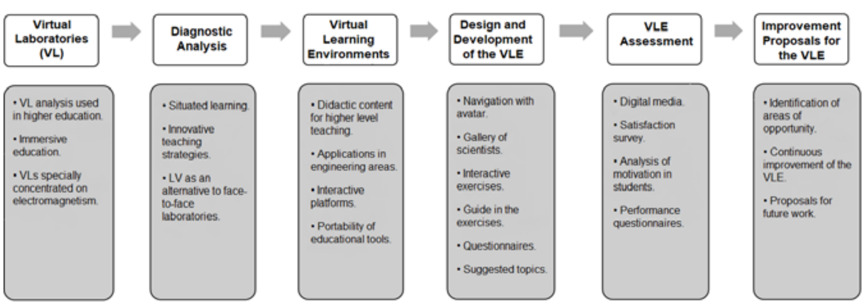
关键词：虚拟实验室；电磁学；工程;沉浸式教育；情境学习；教育技术；虚拟现实。

Introduction

This article describes the research carried out on the design and implementation of a Virtual Laboratory of Electromagnetism (VLE) applied to the teaching of fundamental concepts of electromagnetism at the higher education level. An own methodology was used to analyze the important and necessary previous aspects to implement a proposal for a didactic strategy using a virtual laboratory that supports the teaching process of electromagnetism. In an initial stage, the characteristics and background of virtual laboratories for teaching Physics and their applications in electromagnetism were analyzed, as well as the global trends of immersive education applied at higher education levels. Subsequently, the technological and design aspects expected by the university community studied in this research when using a virtual laboratory were analyzed, which would be useful for teaching electromagnetism topics and their applications in engineering areas. Based on this analysis, an educational intervention strategy based on the situated learning approach is proposed due to the specific characteristics found in the previous diagnostic surveys for the case study. For the process of designing the virtual educational environment that includes the Virtual Laboratory of Electromagnetism, various elements are proposed in accordance with the situated learning approach that are described later. The use of interactive platforms and accessible software that fostered the development of the portable virtual laboratory was weighed up due to the moment of health contingency that was experienced at the time of the investigation. The VLE developed was introduced to a group of the student community of the Faculty of Engineering campus Ixtaczoquitlán, of the Universidad Veracruzana in Mexico for its assessment through satisfaction surveys carried out on users. Aspects such as the motivation and performance of the engineering students who used the VLE were analyzed through exit questionnaires and evaluation of the understanding of electromagnetism concepts. Once the performance parameters of the students surveyed were identified, as well as the areas of opportunity of the VLE, a series of elements are proposed to be considered for future research in order to establish precedents in the design of virtual laboratories specially conceived for the teaching of electromagnetism and its applications in engineering areas. The strategy used to carry out this research is summarized in the diagram of Figure 1.

Figure 1

Strategy carried out for the design and implementation of the Virtual Laboratory of Electromagnetism (VLE).



This research is presented and organized in the sections that are described below. Section 1 describes the background of virtual laboratories, as well as the main difficulties that arise in the teaching of electromagnetism in relation to its application in the area of engineering. Section 2 presents the characteristics of the context of the case study in which a general diagnosis was developed. After the diagnosis of the case study, section 3 describes the proposal for a virtual learning environment under the situated learning approach, to establish the design guidelines of the VLE. Section 4 describes the main aspects used in the design and development of the Virtual Laboratory of Electromagnetism, as well as the elements that comprise it. Section 5 describes in detail the applied educational intervention, as well as its assessment in the case study. Section 6 presents the results obtained prior to their analysis in section 7. Finally, the conclusions are presented in section 8 and the recommendations for future work in section 9.

Virtual Laboratories

Virtual laboratories are used as attainable educational strategies, as they are designed so that the student can easily interact with a wide variety of integrated tools, allowing enough time to carry out the included practical sessions or simulations and, at the same time, to repeat the exercises as many times as necessary to reaffirm the concepts studied (Potkonjak, 2016). Currently, there are several difficulties, such as the level of immersion (Dengel & Mägdefrau, 2020), the representation of content (Liu et al., 2015), and the diversity of application areas (Lynch & Ghergulescu, 2017), for these tools to be efficient in the construction of abstract concepts that require complex analysis and adequate guidance on behalf of the professors.

Difficulties when Learning Electromagnetism

Electromagnetism is a discipline of Physics that presents special difficulties for its learning (Agudelo et al., 2019) because it requires the understanding of abstract phenomena, which are difficult to perceive in a classroom or in a laboratory. Concepts such as electric force, electric field, and electromagnetic field require conceptual diagrams and simulations in the teaching-learning process, generally represented by two-dimensional diagrams, through drawings on the blackboard or shown in textbooks. There are various graphic alternatives for teaching these concepts (Batuyong & Antonio, 2018). However, the tools in which interactive graphic simulations are presented allow to show the interaction of electric charges and the effect of electromagnetic fields more efficiently (Pontes, 2017), which are also interesting for the students and extremely useful for the teachers. However, most of the existing interactive applications do not have options such as on-site guided orientation, so that the students can identify the usefulness of the tools (Yunzal et al., 2020; Maheshwari & Maheshwari, 2020). Existing virtual applications or animations only present an interactive environment that most of the time does not include pre- and post-practice analysis. The guide within the tool is useful for the students to acquire a meaningful learning by leading a metacognition process that encourages observation, analysis, and the generation of their own conclusions. In this research, the situated learning approach is applied as a didactic proposal using Virtual Laboratories in the instructional process of teaching basic concepts of electromagnetism focused on undergraduate engineering students at the Universidad Veracruzana (UV) in Mexico.

Case Study

This research was developed at the Faculty of Engineering, Ixtaczoquitlán campus (FIcI) of the Universidad Veracruzana in the Orizaba-Córdoba region. This faculty offers four educational programs: Mechatronics Engineering, Civil Engineering, Industrial Engineering, and Electrical Mechanical Engineering. The FIcI faculty has several laboratories to meet the educational needs of its programs, which share common educational experiences. One of the laboratories in the basic training area is the Physics Laboratory, which is essential for the four educational programs of the FIcI. Although there are appropriate areas for the experimentation of the basic concepts of electromagnetism, there are several problems that are identified during the laboratory practical sessions. For the purposes of this research, a student population of more than 90 engineering students was considered, to whom various information collection instruments were applied via digital media through surveys.

Preliminary Diagnostic Survey (PDS)

In order to identify the perception of the FIcI students about the practical sessions in presence-based laboratories, and subsequently have enough elements to compare those with virtual laboratories, a Preliminary Diagnostic Survey (PDS) was carried out.

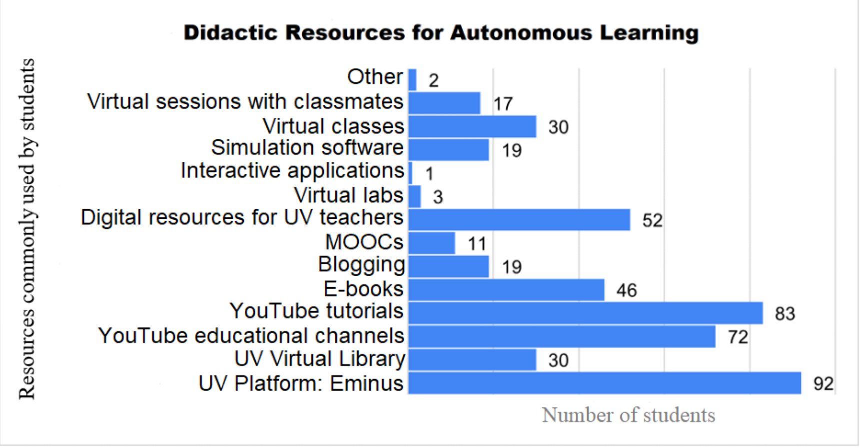
The PDS was carried out by digital means through Internet Forms distributed among the institutional accounts of a FIci student population of 104 students, during the school period of February-July 2020. The survey analyzed various indicators to determine the background and characteristics needed for the design of a Virtual Laboratory based on the situated learning approach which would address the main difficulties of the student community, due to the contingency of the COVID-19 pandemic, in accordance with that reported by (Steele & Schramm, 2021).

In the PDS, various types of questions were asked, considering open questions, Likert scales, and dichotomous responses to identify quantitative and qualitative indicators, such as: Internet connection time, Internet connection means used (PC , mobile phone, tablet), weekly study time, digital media commonly used by the students for autonomous learning, preference of teaching modality, prior knowledge of the use of virtual laboratories, characteristics that the students prefer in a virtual teaching session, limitations of laboratory practical sessions in the presence-based modality, time availability for the laboratory practical sessions, access to specialized laboratory equipment, and suggestions for teaching strategies involved in the laboratory practical sessions.

Figure 2 shows that at the Faculty of Engineering campus Ixtaczoquitlán (FIcI), 88.46% of the students surveyed use Eminus: the institutional platform used to access the contents of educational experiences. Regarding the open platforms available on the Internet, 79.81% use YouTube to learn, but only 69.23% do so through educational channels. While most students use open digital media for their autonomous learning process, 50% of the students also use digital content produced by their own professors. Therefore, it is to be expected that the students also need guidance from their professors in their learning process.

Figure 2

Previous diagnostic survey applied at the FIcI in May 2020.



Lack of Virtual Laboratories for Engineering

The PDS carried out reveals clear evidence that this technology is still unknown by the FIcI students, since only 2.88% mentioned the use of virtual laboratories for autonomous learning. 34% of the students mentioned knowing what virtual laboratories are, but they also indicated that they have not had the opportunity to use any of them. Among the students surveyed, 65% mentioned not knowing what a virtual laboratory is.

Virtual Learning Environment through VLE

The Preliminary Diagnosis Survey (PDS) was essential to learn about the perspective of the students regarding their experience in the laboratories in presence-based mode. Prior to the design of the Virtual Laboratory of Electromagnetism (VLE), the characteristics of situated learning that apply to engineering education were studied. The characteristics of situated learning that were considered most important for the development of the VLE are described below.

According to the situated learning approach, didactic activities focused on the student are preferred (Gómez-Gómez & Hernández, 2015) and those focused on the metacognitive process that should be encouraged in the student through adequate tutoring in the educational process (Hevia-Arime & Fueyo-Gutiérrez, 2018).

The PDS carried out was very important since it allowed the development of new didactic strategies that involved the following aspects:

Activities focused on the student. Situated learning values teaching strategies that allow students to develop an activity autonomously and collaboratively. Laboratory practical sessions are usually developed in work teams where not all team members may have the same opportunity to use the equipment, interact with it, or may even experience different learning processes. Focused teaching tools are required which the student can use autonomously and with the availability to repeat the experiments individually as many times as necessary, without depending on a physical location in the laboratory or a schedule of practical sessions. In addition, the didactic tools must include sufficient explanation so that the student can develop the learning activities independently and assisted at a distance.

New learning environments within specific virtual laboratories. Virtual laboratories are an alternative in circumstances with limited educational infrastructure or, in the case of this research, the COVID-19 contingency that occurred in 2020. Although there is already a trend of these focused technological tools in a marketable format (Labster, 2021), there are still institutional limitations to acquire these virtual tools due to licensing or financial issues, and/or the fact that focused virtual laboratories are not offered for most engineering areas. This proposal is presented as a paradigm shift in higher education institutions to promote multidisciplinary efforts in the creation of new educational environments (Guzmán-Luna et al., 2014; Baranov, 2016), although they already exist worldwide, they are still not fully implemented due to limited knowledge of their potential (Infante-Jiménez, 2014).

Efficient Use of Technologies Applied to Knowledge (TAK). The use of TAKs would be more efficient if they were designed through a didactically designed instructional support (Gunawan et al., 2017). In this sense, it is essential that teachers, institutions, and collegiate academic entities work together to develop teaching strategies in which instructional design has a situated learning approach (Aldana-Segura & Arévalo-Valdés, 2018).

Autonomous Learning through Analysis. One of the central objectives of situated learning is that the students can analyze their learning process through metacognition. Consequently, it is suggested to include final evaluations at the end of each practical session. After the final test of each practical session, it is also suggested to carry out complementary readings on related topics experimented in each practical session to encourage the students to investigate the applications of the concepts studied through the VLE in greater depth. According to this approach, learning in virtual educational environments should encourage and support the ability of the students to establish relationships and interpret the results of the learning attained, with their applications in professional settings (Peña, 2016).

Design and Development of the VLE

Based on the situated learning approach described above, the design of the VLE was proposed to promote the prior analysis of the electromagnetism concepts, identifying the areas of engineering in which it has a direct application. The design of the VLE emulates an interactive virtual environment in which the students can navigate using an avatar. The virtual environment represents the FIcI University campus and at the entrance hall it shows a gallery of forefather scientists of electromagnetism, as well as engineering applications, to later enter the area of interactive practical sessions where practical exercises in electromagnetism will be solved.

Design of the Virtual Laboratory of Electromagnetism

A virtual learning environment with a situated learning approach was designed, which allows the students to analyze concepts such as electric force, Coulomb's law, Ohm's law, electromotive force and related applications, through interactive practical sessions accompanied by a final reflective questionnaire, as well as the recognition of the technological applications of each of these concepts of electromagnetism.

The Virtual Laboratory of Electromagnetism (VLE) was designed to introduce questions that lead to an analysis of the concepts acquired prior to practical experimentation, so that the students are better prepared to understand the relationship between the theoretical concepts and the effects related to the experiments that they will practice in the VLE. Interactive practical sessions were planned and designed to allow students to vary the quantities of electrical variables, as well as electrical charges to analyze the effect that these variations have on the fundamental laws of electromagnetism. After completing each of the practical sessions, a questionnaire is presented with analysis questions about the concepts experimented and a score is assigned, so that the students determine whether it is necessary to carry out the experiment again to reaffirm the theoretical concepts.

Another fundamental aspect for the implementation of the VLE in the context described in the case study was that the virtual tool was developed in an accessible and portable platform for the students, which was not limited to its use within institutional facilities. In order to meet the needs of the students regarding the available practice time to carry out exercises and interactive practical sessions in a hybrid learning modality, the VLE was developed through the animation design platform for virtual environments described below.

Development of the Virtual Laboratory of Electromagnetism

The Virtual Laboratory of Electromagnetism was developed with Unity® software, an animation software. Unity® is a cross-platform game engine created by Unity Technologies®. The game engine refers to a software with a series of programming routines that allow the creation, development, and implementation of interactive environments such as a video game. Unity® has been used for the design of interactive virtual environments in which it is possible to include interactive avatars to navigate through the environment in a simple and practical way. Unity® offers the possibility of exporting some previously designed elements so that the adaptation to the dedicated environment is accessible for personalized modification. Unity® software was chosen because it is widely used by various design communities to create interactive environments for both playful and educational purposes. The use of avatars provides serious games for students experiencing an interactive educational environment that will encourage them to practice in the laboratory in a dynamic way.

The Unity® development platform has support for compilation with different types of platforms and offers the possibility of creating portable files to install the VLE on a desktop or mobile device. The trial version was used so that all the students could download and install the VLE in their computers. The initial scene (Figure 3) shows an avatar that can navigate through the FIcI virtual campus into the different sections using the keyboard controls.

Figure 3

Initial scene of the Virtual Laboratory of Electromagnetism.

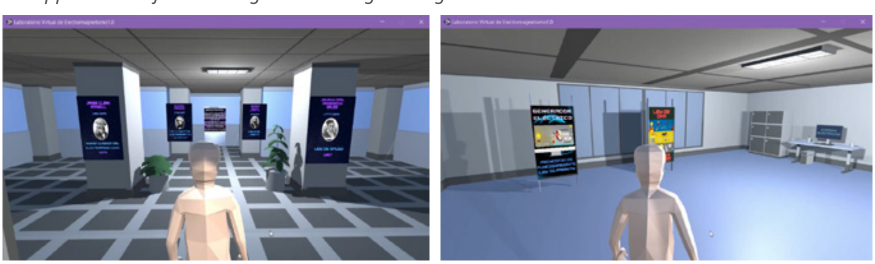
The elements that make up the Virtual Environment of the VLE are described below.

VLE Elements

It was considered very important to show a module called Gallery of Forefather Scientists of Electromagnetism (Figure 4.a) to encourage the students' interest in the scientific advances that have occurred throughout the history of Physics (Perea & Buteler, 2016). In this way, the student can become more aware of the contributions that various scientists have provided for the applications of electromagnetism in Engineering and encourages the analysis of the scientific method that was carried out in each discovery.

Figure 4

Sections of the Virtual Laboratory of Electromagnetism. a) Gallery of scientists. b) Posters related to the applications of electromagnetism in engineering.



a) b)

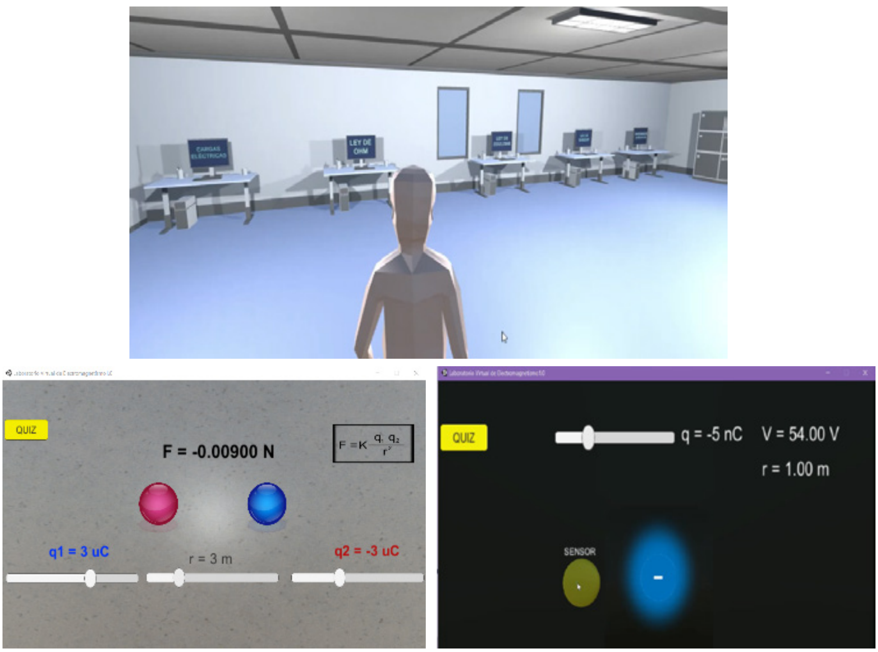
Subsequently, a series of posters are presented (Figure 4.b), showing some of the applications of electromagnetism in engineering. Situated learning is referred to again, since the activities designed in the VLE are not presented separately but are associated with engineering activities to facilitate more significant learning. The scientists' gallery and the electromagnetism applications hall are the prelude to the virtual laboratory where the simulated experiments are found through interactive practical sessions.

Interactive Practical Sessions

The virtual learning environment allows the user to navigate through an avatar to access the VLE that presents five different practical sessions with interactive exercises on fundamental topics of electromagnetism such as: electric force, Ohm's law, Coulomb's law, Faraday's law, and applications of electromotive force. To carry this out, the user will access interactive windows with a didactic methodology that involves six stages (Figure 5): 1-Welcome, 2-Purpose of the practical session and related topics, 3-Instructions for the practical session and discussion questions, 4-Interactive practical session, 5-Subsequent analysis questionnaires, 6-Evaluation, and suggestion of complementary topics.

Figure 5

Example of the virtual environment of a VLE practical session.



At the VLE, trigger questions were presented before the practical experimentation to encourage analytical observation of the effects of the interacting conceptual elements that the student will experience in the practices of the LVE. In the interactive practical sessions, the student can modify magnitudes and electrical charges to analyze the effect that these variations have on the fundamental laws of electromagnetism. After completing each of the practical sessions, a questionnaire is presented in which analysis questions are asked about the concepts experimented and a score is assigned, so that the student knows whether it is necessary to perform the experiment again to reaffirm the theoretical concepts.

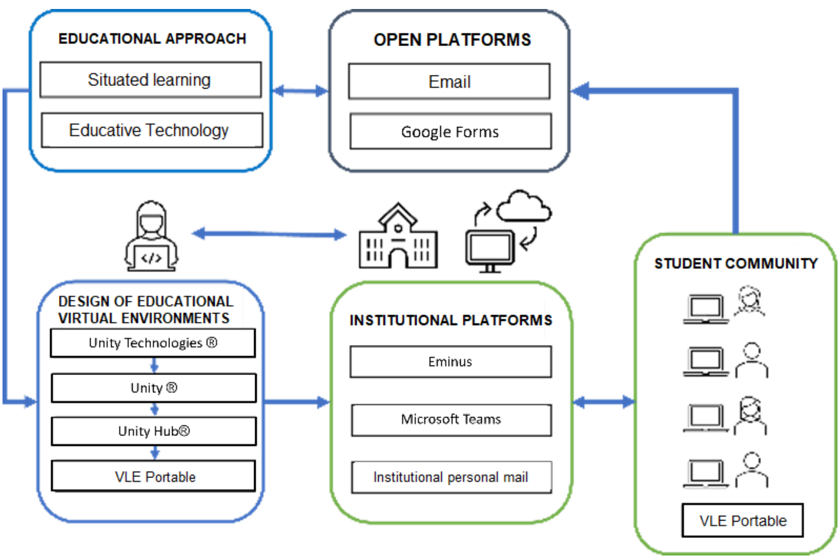
VLE Implementation and Evaluation

The educational intervention strategy consisted of the use of the Virtual Laboratory of Electromagnetism (VLE) by a population of students from different engineering programs of the Faculty of Engineering of the Universidad Veracruzana, in the Orizaba-Córdoba region, during the SARS-Cov2 pandemic contingency period in the August-December 2020 academic period.

The student population was chosen considering those students who were attending subjects related to electromagnetism and its applications. Therefore, the VLE was shared with a group of 95 students, which included 80 male students (82.4%) and 15 female students (15.8%). The application of the Virtual Laboratory of Electromagnetism was established after a previous period in which the basic concepts of electromagnetism were analyzed. Therefore, the VLE was used as a complementary didactic strategy to consolidate the concepts previously studied. Given the need for a didactic strategy that could be used openly, without restrictions, and remotely due to health contingencies, institutional communication platforms were used. The institutional mail and the Eminus and Microsoft Teams platforms were used to provide the guidelines for the installation and application of the didactic tool. Each student used the free and portable version of the VLE and installed it in a personal computer. Figure 6 illustrates the scheme of the technological elements used in the educational intervention.

Figure 6

Architecture of the technological elements involved in the implementation of the VLE.



Analysis of the Obtained Results

A quantitative and qualitative analysis was developed to measure the effectiveness of the didactic proposal implemented through the Virtual Laboratory of Electromagnetism, to evaluate several factors, such as the performance in the achievement of the fundamental concepts of electromagnetism, the perception of the students about the new teaching strategies involving virtual laboratories, and the motivation to use tools similar to the VLE in the future (Radianti, 2020). A sample of ninety-five engineering students who used the VLE by institutional means of communication for contingency reasons was surveyed. The results obtained for each of the items to be evaluated are described below.

Learning performance. In the survey that was carried out, the performance of the students was monitored through questionnaires at the end of each simulation to monitor whether the learning of the concepts of electromagnetism was reinforced. Several factors were analyzed: level of complexity of the questionnaires, response attempts, concept of electromagnetism involved, simulation mode related to the question of the questionnaire, influence of the directions of the simulation, and perception of the virtual environment. The performance of the students in each simulated experiment was analyzed based on the aspects mentioned. Table 1 summarizes the performance of the students in each practical session, describing the percentage of students who answered correctly to all the questions related to the theoretical concepts of electromagnetism.

Table 1

Performance results of the students who used the VLE.

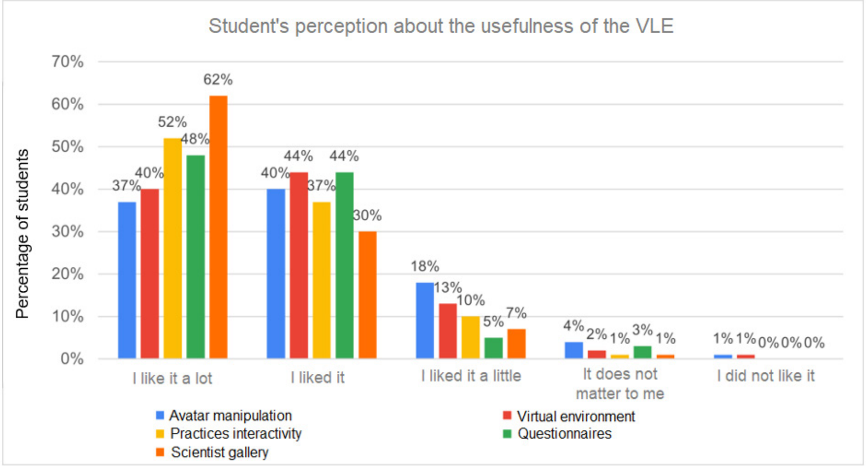
VLE Practical Session	Percentage of students who answered correctly
1. Electrical force	81.1%
2. Ohm's Law	52.6%
3. Coulomb's Law	85.0%
4. Faraday's Law	83.2%
5. Fem's Applications	97.0%

It can be observed that the practical sessions that presented a greater number of interactive elements, as in practical session 5, provide better performance results. On the other hand, several difficulties were found in evaluating the performance of practical session 2, such as a greater uncertainty in the graphical representation of the experiment, which translated into a greater difficulty for the students to identify the applications of Ohm's Law.

Students' perception of the virtual environment. In this research it was very important to identify the opinion of the students regarding the experience with the VLE, for which several questions were asked with a Likert scale, referring to the use of the avatar, the interactive modality in the practical sessions, the design of the virtual environment, post-practice discussions, as well as information on the Forefather Scientists of electromagnetism. The results indicate that the VLE had a general acceptance in each of its sections (Figure 7).

Figure 7

Perception of the students surveyed about the use of the elements of the Virtual Laboratory of Electromagnetism.



Most of the students considered the experience with the VLE satisfactory. However, they also made suggestions to improve the manipulation of the avatar, such as optimizing the keyboard controls for movement in the virtual campus navigation.

Discussion

Based on the survey given to the students who used the Virtual Laboratory of Electromagnetism, several factors were identified that provide extremely useful information for the improvement and adjustment of the VLE in the future. The most outstanding ones are listed below.

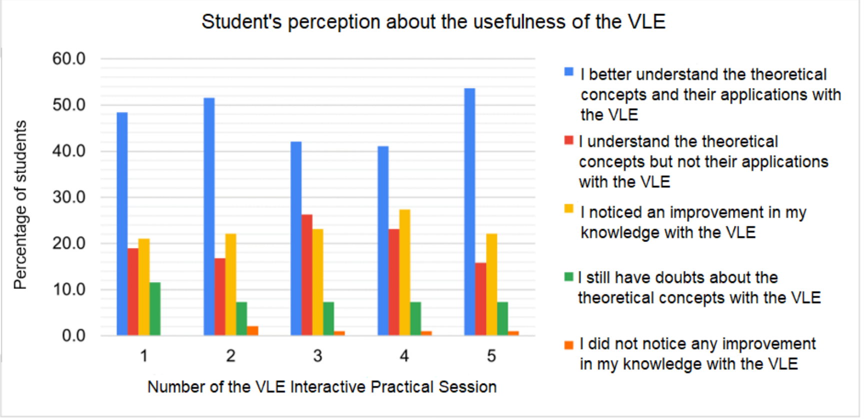
Use of the virtual environment. According to the opinion of the students surveyed at the end of the use of the Virtual Laboratory of Electromagnetism, it was found that the use of the avatar is one of the elements that the students liked the most. Navigation through the virtual environment is more interactive thanks to the use of the avatar. However, several areas for improvement suggested by the students were found. One of them is to improve the controls that manipulate the avatar so that its movements are more fluid within the virtual environment. Another aspect that the students mentioned is the possibility of customizing the characteristics of the avatar. Although the appearance of the avatar does not affect the interaction of the electromagnetism practical sessions, it is a feature that enables students to make the educational immersion a more personalized and visually appealing experience.

Gallery of the Forefather Scientists of Electromagnetism. The surveyed students expressed that the information from the scientists was interesting and relevant to contextualize their contributions to electromagnetism, and that they would like to have scenes of interaction with these scientists within the same environment.

Interaction with the electromagnetism practical sessions. The survey shows a favorable scenario regarding the usefulness of the five experimental practices to understand the basic concepts of electromagnetism and its applications. Figure 8 compares the general perception of the students who used the Virtual Laboratory of Electromagnetism, considering it as an educational resource for the construction of knowledge and the application of electromagnetism.

Figure 8

Students' perception about the usefulness of the VLE.



In addition, the students suggested more practical sessions with similar electromagnetism concepts for a better understanding of the applications of the electromagnetism concepts. For future versions of the VLE, it is suggested to increase the number of practical sessions and interactive exercises.

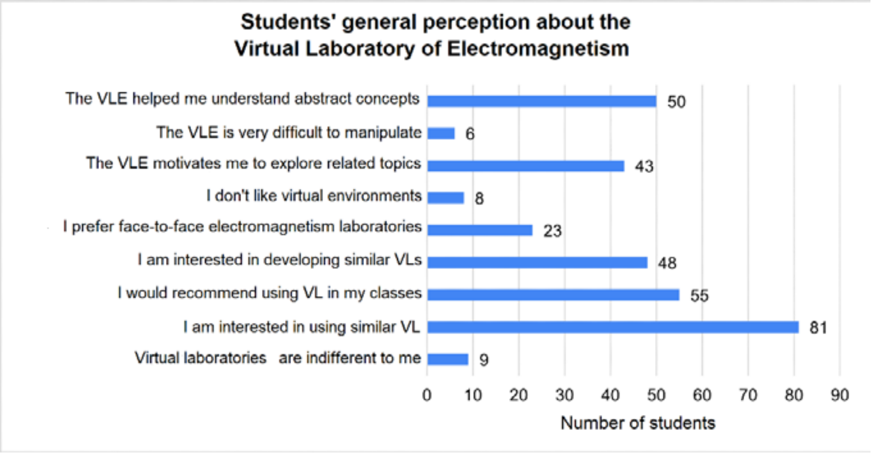
Evaluation of the learning obtained. During this investigation it was observed that the evaluation after the use of educational technological tools is extremely important to determine their usefulness and relevance as didactic strategies. The students expressed that the questionnaires could include a greater number of questions or also include interactive challenges after having understood each practical session to reaffirm the knowledge acquired.

Development of virtual educational environments. The purpose of this research is to highlight that multidisciplinary work is necessary to develop innovative educational tools that address new challenges in higher education contexts. It has also been crucial for the development of this type of virtual laboratories to consider the demands of the new generations of students in terms of their interests, technological skills, the infrastructure available to promote autonomous learning, and that they can be useful as a complement to presence-based classes and laboratories. The survey also reveals a strong interest among the engineering students surveyed to participate in the software development of these technological tools. The interaction between the use of currently available animation technological tools must be accompanied by a teaching planning to achieve the learning objectives.

Student Motivation to Use Virtual Laboratories. Finally, the students were asked how they perceived the use of virtual laboratories as a teaching tool, as well as if they would be interested in using them in the future to learn with this type of learning strategies. The results are promising (Figure 9) in the case study, where even some of the engineering students reported that they would be interested in developing projects that use this type of virtual educational environment in future research projects.

Figure 9

Students' general perception about their experience in the use of the VLE.



Conclusions

This research concludes that it is possible to design and implement virtual laboratories especially focused on areas of applied Physics in engineering education using animation software, which are attractive to the students, considering them as a useful interactive educational tool. It is important that virtual educational environments are not only visually attractive for the students, but that they are a space where the construction of knowledge is facilitated by relating the historical context, the theoretical concepts, and the applications of electromagnetism through experimentation under a specially designed teaching strategy.

The design of virtual environments focused on the area of engineering involves several scenarios to apply them as a common tool in each institution. There are some aspects that are interesting research topics such as the level of immersion of the virtual environment, the participation of the students in an interactive environment, the educational strategies to simulate suitable professional engineering environments and how teachers could design virtual laboratories so that the students solve problems inherent to the area of engineering efficiently. Therefore, the proper process of instructional design of didactic strategies through immersive educational technologies that involve multidisciplinary work in educational technology should be considered.

Future works

Future research will focus on improving avatar navigation as well as interactivity in practical exercises to increase the understanding of abstract concepts such as electromagnetic fields. Another aspect suggested is to incorporate an interactive gallery with information about the Forefather Scientists of electromagnetism to encourage the students to investigate more about the scientific method used to develop applied technology based on the electromagnetic theory. The trial version of Unity restricts the number of interactive scenes that can be included in the laboratory, so the possibility of increasing the functions that can be configured with this software will be considered and even search for alternatives on various platforms to create similar virtual educational environments.

References

Agudelo, J., Méndez, G., & Melo, A. (2019). Difficulties in the teaching-learning relationship of electromagnetism in introductory university-level courses: Case of the Catholic University of Colombia. *Meeting of Basic Sciences* (pp. 31-41). https://hdl.handle.net/10983/25223

Aldana-Segura, W., & Arévalo-Valdés, J. (2018). *Laboratory of Pedagogical Innovation of Virtual Education a strategy for the development of significant learning experiences in the acquisition of competencies in virtual environments.* UNAM. https://reposital.cuaieed.unam.mx:8443/xmlui/handle/20.500.12579/5092

Baranov, A. V. (2016). Virtual students' laboratories in the physics practicum of the Technical University. *13th International Scientific-Technical Conference on Actual Problems of Electronics Instrument Engineering (APEIE) IEEE* (pp. 326-328). IEEE. https://doi.org/10.1109/APEIE.2016.7802287

Batuyong, C. T., & Antonio, V. V. (2018). Exploring the effect of PhET interactive simulation-based activities on students' performance and learning experiences in electromagnetism. *Asia Pacific Journal of Multidisciplinary Research, 6*(2), 121-131.

Dengel, A., & Mägdefrau, J. (2020). Immersive Learning Predicted: Presence, Prior Knowledge, and School Performance Influence Learning Outcomes in Immersive Educational Virtual Environments. *6th International Conference of the Immersive Learning Research Network (iLRN)* (pp. 163-170). IEEE.

Gómez-Gómez, J. E., & Hernandez, V. L. (2015). Interactive architecture as a support for situated learning in engineering education. *Engineering Education Journal, 10*(20). https://doi.org/10.26507/rei.v10n20.575

Gunawan, G., Harjono, A., Sahidu, H., & Herayanti, L. (2017). Virtual laboratory to improve students' problem-solving skills on electricity concept. *Journal Pendidikan IPA Indonesia, 6*(2), 257-264. https://doi.org/10.15294/jpii.v6i2.9481

Guzmán-Luna, J. A., Torres, I. D., & Bonilla, M. L. (2014). A practical case of application of a methodology for virtual laboratories. *Scientia et technica, 19*(1), 67-76.

Hevia-Arime, I., & Fueyo-Gutiérrez, A. (2018). Situated learning in the design of virtual learning environments: a peer learning experience in a community of practice. *Open Classroom, 47*(3), 347-354. https://doi.org/https://doi.org/10.17811/rifie.47.3.2018.347-354

Infante-Jiménez, C. (2014). Pedagogical proposal for the use of virtual laboratories as an activity in theoretical-practical subjects. *Mexican Journal of Educational Research, 19*(62), 917-937.

Labster. (August 25, 2021). *Labster*. https://www.labster.com/research/

Liu, D., Valdiviezo-Díaz, P., Riofrio, G., Sun, Y. M., & Barba, R. (2015). Integration of virtual labs into science e-learning. *Procedia Computer Science, 75*, 95-102.

Lynch, T., & Ghergulescu, I. (2017). Review of virtual labs as the emerging technologies for teaching STEM subjects. *INTED2017 Proc.11th Int Technol. Educ. Dev. Conference*, (pp. 6-8). https://doi.org/10.21125/inted.2017.1422

Maheshwari, I., & Maheshwari, P. (2020). Effectiveness of immersive VR in STEM Education. (pp. 7-12). *Seventh International Conference of Information Technology Trends (ITT)*. https://doi.org/10.1109/ITT51279.2020.9320779

Peña, J. Z. (2016). Context in the teaching of science: analysis of the context in the teaching of physics. *Gondola, Science Teaching and Learning, 11*(2), 193-211.

Perea, M. A., & Buteler, L. M. (2016). The use of the history of sciences in the teaching of physics: an application for electromagnetism. *Gondola, Science Teaching and Learning, 11*(1), 12-25.

Pontes, A. (2017). Using interactive simulations to understand the electric current model. *X International Congress on Research in Science Education,* (pp. 4371-4377). Sevilla.

Potkonjak, V. G. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education, 95*, 309-327.

Radianti, J. M. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education, 147*, 103778.

Steele, A. L., & Schramm, C. (2021). Situated learning perspective for online approaches to laboratory and project work. *Proceedings of the Canadian Engineering Education Association (CEEA).*