CAPÍTULO 9

TEACHING ELECTROMAGNETICS CONCEPTS IN HIGHER EDUCATION USING SITUATED LEARNING AND VIRTUAL LABORATORY TECHNOLOGY

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ABSTRACT: In recent years, the combination of virtual laboratories and situated learning has emerged as an innovative didactic strategy that improves engineering education. Virtual laboratories provide a flexible and accessible platform for students to conduct experiments and learn complex concepts in a safe manner, which is complemented by the situated learning methodology that emphasizes the importance of contextualizing learning in real-life situations, resulting in an effective blend for learning. On the other hand, electromagnetism is a fundamental subject in engineering education, traditionally taught through theoretical classes and physical experiments in laboratories. However, these methods have limitations, such as the need for expensive equipment, safety risks, and limited access to laboratory resources. To overcome these challenges, virtual laboratories have emerged as a viable alternative for teaching, providing a simulated environment where students can explore different scenarios, conduct experiments, and visualize complex concepts that are difficult to observe in traditional laboratory settings.

This chapter presents a comprehensive approach to teaching electromagnetism in engineering education, combining virtual laboratories and situated learning through the design and implementation of a Virtual Electromagnetism Laboratory. The laboratory aims to provide a rich and immersive educational experience that facilitates the learning of electromagnetism for engineering students, all from the perspective of situated learning, contextualizing the learning process in real-life situations, allowing students to develop critical thinking skills and problem-solving abilities

KEYWORDS: *Situated learning*, *Virtual Laboratory*, *Engineering*, *Electromagnetism*.

1 I INTRODUCTION

This chapter describes the results obtained from the application of a combination of situated learning methodology and virtual laboratories to teach some fundamental topics in electromagnetism, such as *electric force, Ohm's law, Coulomb's law, Faraday's law*, and the concept of *electromotive force* (EMF). To achieve this, a Virtual Electromagnetism Laboratory (VEL) was designed and implemented, which was applied to the engineering teaching process using the situated learning methodology.

1.1 Situated Learning

To speak of situated learning is not only to refer to learning contextualized in social and historical moments, but goes beyond that, since, in the face of learning problems, psychology also offers a variety of answers, which are not limited to individual logic or the results of the processes, which to this day is the method that has been followed most often to understand these phenomena. Today, the question of how to learn is not only addressed through the validation of neurological or pedagogical phenomena, we now know that learning is structured within complex social processes, which have been studied by authors belonging to the fields of education, psychology and sociology, demonstrating that learning is not a matter that can be understood only by what happens at the individual level in the student's mind, but rather, it is part of a series of processes carried out in a given context, which determine not only the results but also the relationships between all those involved in the educational model.

1.2 Virtual Laboratories

Currently the use of virtual laboratories in education has increased, evolving from basic simulators with little graphic content, to very complex and enriched with interactive content and with many possibilities to recreate situations that simulate real laboratories, thus allowing to incorporate them into multiple teaching sequences, at different levels of education, since by their characteristics students can interact easily with a wide variety of tools that they incorporate, which added to the availability of time, However, there are also several difficulties for them to be accepted as substitutes for real laboratories, highlighting for example the level of immersion experienced by students [1], which often makes them be taken as something fun or entertaining rather than as a tool designed for learning; The representation of the contents [2] is also an obstacle, since there are still few virtual laboratories that cover complete syllabuses of a subject, which results in a limited diversity of application areas [3]. Therefore, for these tools to be efficient in the construction of abstract concepts such as those that integrate electromagnetism, a complex analysis and adequate guidance by teachers are required.

1.3 Obstacles to learning electromagnetism

Electromagnetism is part of Physics and historically has represented difficulties for its learning [4] because to be learned it requires the understanding of abstract phenomena, which are difficult to perceive in a classroom using a blackboard or through a laboratory practice. Concepts such as electric force, electric field and electromagnetic field require diagrams and conceptual simulations in the teaching-learning process, and are usually represented by two-dimensional diagrams, through drawings on the blackboard or shown in textbooks through 2D diagrams. Although there are several graphical alternatives for teaching these concepts [5], the tools that present interactive graphical simulations allow to show in a more effective way [6] the interaction of electric charges and the effect of their electromagnetic fields, which in addition to capturing the attention of students, become very useful tools for teachers. However, most of the interactive applications used in many virtual laboratories do not have options such as guided guidance or intelligent tutors, so that students can identify the usefulness of the tools [7] [8]. Existing virtual applications or animations present only an interactive environment that most of the time does not include pre- and post-practice analysis. The guidance within the tool is useful for students to acquire meaningful learning by leading a metacognition process, which stimulates observation, analysis and generation of their own conclusions. In this research a situated learning approach is applied as a didactic proposal using Virtual Laboratories in the instructional process of teaching basic concepts of electromagnetism focused on engineering students.

2 | CASE STUDY

The research presented in this chapter was conducted in a Faculty of Engineering (FI) belonging to the University of Veracruz in Mexico, considering the fact that one of the laboratories of the basic training area is the Physics Laboratory, which serves four educational programs: Mechatronics Engineering, Civil Engineering, Industrial Engineering and Electrical Mechanical Engineering and although there are spaces for experimentation to learn the basic concepts of electromagnetism, there are still several difficulties that arise at the time of performing laboratory practices, such as lack of equipment and time of uses to serve all students. During the development of the research, initially the perception that students had about the practices in face-to-face laboratories was identified, and to have elements of contrast with the virtual laboratories, a Preliminary Diagnostic Survey (PDS) was carried out. The PDS was applied by means of digital tools through Internet forms shared through institutional accounts to a population of 104 students of the FI, in the academic period February - July 2020. As a result of the application of the survey, it was possible to analyze various indicators, which allowed establishing the necessary background and characteristics to be considered for the design of the proposed Virtual Laboratory, under the approach of situated learning, which would address the main problems of the student community, which increased due to the contingency for the COVID- 19 pandemic, according to what was found by [9]. In the PDS diagnostic survey, a series of open questions were asked, measured using the Likert scale and with dichotomous answers to identify quantitative and qualitative indicators such as: time spent online, method of internet access, devices used for internet connection (PC, cell phone, tablet), weekly hours dedicated to study; digital media or educational tools used by students for autonomous learning, preference in the teaching modality, knowledge and use of the virtual laboratory. As well as, characteristics that students prefer in a virtual teaching session, limitations to perform practices in face-to-face laboratories, availability of time to perform laboratory practices, access to specialized laboratory equipment, as well as suggestions of didactic strategies involved in laboratory practices.

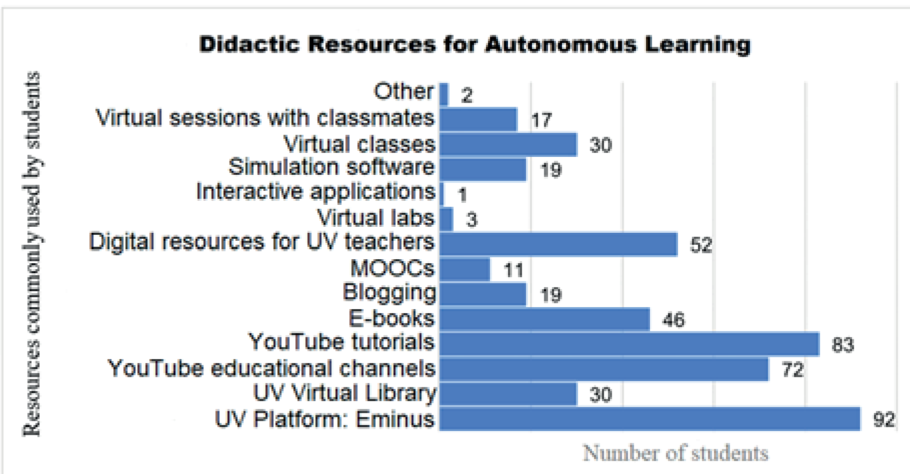

Figure 1. Source: PDS diagnostic survey, via Forms on independent study methods applied to students of the FI of the Universidad Veracruzana in May 2020.

It was observed that at FI, 88.46% of the students surveyed use Eminus: institutional platform through which they access the contents of the educational experiences. Regarding open platforms available on the Internet, 79.81% use YouTube to study, but only 69.23% do so through educational channels. While most students use open digital media for the independent learning process, 50% of students also use digital content created by their own teachers. Therefore, it is assumed that students also require the guidance of teachers in the learning process.

2.1 Insufficiency of virtual laboratories in engineering

The PDS conducted reveals clear evidence that this technology is still unknown by

FI students, since only 2.88% mentioned the use of virtual laboratories for autonomous learning. The 34% of the students mentioned awareness of what virtual laboratories are, but they also indicated that they have had no opportunity to use any of them. Among the students surveyed, 65% mentioned that they did not know what a virtual laboratory is.

3 I DESIGN OF THE ELECTROMAGNETISM VIRTUAL LABORATORY (EVL)

After the diagnostic survey results were obtained, the characteristics that the Electromagnetism Virtual Laboratory should incorporate were identified, as described in the following paragraphs.

3.1 Characteristics based on the situated learning approach

In accordance with the situated learning approach, didactic activities are preferred that are student- centered [10] and focused on the metacognitive process that the student should be encouraged to develop by means of adequate mentoring in the educational process [11]. The PDS survey realized, was very important since it permitted the development of new didactic strategies that implied the following aspects:

Student-centered activities. Specific didactic tools are required that can be used independently and remotely, where students should be able to develop their autonomous learning process without space and time constraints.

New learning environments involving 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.Virtual laboratories are an alternative in circumstances with limited educational infrastructure or in the case of this research, the COVID-19 contingency that occurred last year. Even though there is already a tendency of these dedicated technological tools in a marketable form [12], there are still institutional limitations to acquire these virtual tools due to licensing or financial issues and/or the fact that no dedicated virtual laboratories are offered for most of the engineering areas. In addition, the proposal is presented as a paradigm shift in higher education institutions to promote multidisciplinary efforts in the creation of new educational environments [13] [14], although they already exist globally, they are not yet fully implemented because of a limited knowledge of their potential [15].

Use of technologies applied to knowledge (TAK) in an efficient manner. The use of TAK would be more efficient if they were designed by means of didactically designed instructional support [16]. In this regard, it is essential that teachers, institutions, and collegiate academic entities work together to develop didactic strategies in which the instructional design has a focus on situated learning [17].

Independent learning by means of analysis. According to this approach, learning in virtual educational environments should encourage and support the students' ability to establish relationships and interpret the results of the learning obtained, with their applications in professional scenarios [18].

3.2 Virtual Learning Environment design

The design of the EVL was developed using Unity® animation software, which is a multiplatform video game engine created by Unity Technologies. This software has been used for the design of interactive virtual environments in which it is possible to include avatars to navigate in the virtual environment in a simple and practical form. Unity® has the possibility of exporting some previously designed elements so that the adaptation to the dedicated environment is accessible for custom modification. The free version was used to develop an environment that emulates the university campus where the EVL is settled. The development platform has support for compilation with different types of platforms and provides the possibility of creating portable files to install the LVE on a desktop computer or mobile device. The free version was used to allow all students to download and install LVE on their computers. The opening scene (Figure 2) shows an avatar that can navigate through the virtual campus to the different sections using keyboard controls.

Figure 2. Opening scene of the Electromagnetism Virtual Laboratory

Source: Own elaboration

3.3 Guided interactivity

It was considered extremely important to display a module called gallery of scientists precursors of electromagnetism (Figure 3a) to encourage students' interest in the scientific advances that have been made throughout the history of physics [19]. Hence, the student may become more conscious of the contributions that diverse scientists have provided for the applications of electromagnetism in engineering.

a) **b)**

Figure 3. a**)** Gallery of scientists. **b)** Posters related to applications of electromagnetism in engineering at the Electromagnetism Virtual Laboratory.

Source: Own elaboration

Subsequently, a series of posters are presented (Figure 3.b), displaying some of the applications of electromagnetism in engineering. Situated learning is alluded once again, since the activities designed in the EVL are not presented separately, but rather are associated with engineering activities in order to facilitate more meaningful learning. The gallery of distinguished scientists is the gateway to the virtual laboratory where the simulated experiments are located.

3.4 Laboratory interactive practices

The EVL allows the user to navigate through an avatar to access five different practices that present interactive exercises on fundamental electromagnetism topics such as: electric force, Ohm's law, Coulomb's law, Faraday's law, electromotive force applications. For this, the user will access interactive windows with a didactic methodology that involves six stages (Figure 4): 1. Welcome, 2- Purpose of the practice and related topics, 3-Practice directions and discussion questions, 4-Interactive practice, 5- Questionnaires for further analysis, 6- Assessment and suggestion of complementary topics.

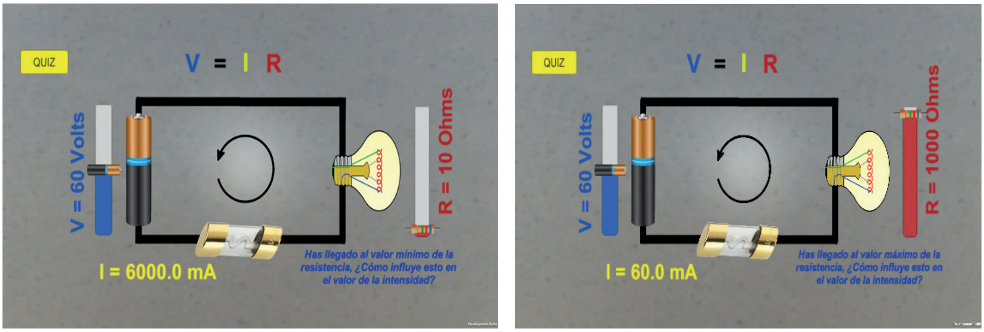

Figure 4. Example of laboratory practice environment in the EVL of the FI of the Universidad de Veracruz. Source: Own elaboration

In the EVL, trigger questions were presented prior to the practical experimentation to encourage the analytical observation of the effects of the interacting conceptual elements that the student will experience in the EVL practices. In the interactive practices the student can modify magnitudes and electric charges to analyze the effect that these variations have on the fundamental laws of electromagnetism. After performing each of the practices, a quiz is presented in which analysis questions about the concepts experienced are asked and a score is assigned, to allow the student to know if it is necessary to perform the experiment again to reaffirm the theoretical concepts.

4 I IMPLEMENTATION AND EVALUATION OF THE EVL

The instructional intervention strategy involved the use of the Electromagnetism Virtual Laboratory (EVL) by a population of students from different engineering programs of the Faculty of Engineering of the University of Veracruz, in the Orizaba - Cordoba region, during the pandemic contingency period due to SARS-Cov2 in the academic period August - December 2020.

Student population was chosen considering those students who were studying courses related to electromagnetism and its applications. Therefore, the EVL was shared with a group of 95 students, which included 80 male students (82.4%) and 15 female students (15.8%). Application of the electromagnetism virtual laboratory was established after a previous period where basic electromagnetism concepts were analyzed. Therefore, the EVL 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 at a distance due to health contingencies, the institutional communication platforms were used. Institutional mail, the Eminus and Microsoft Teams platforms were used to provide guidelines for the installation and application of the didactic tool. Each student used the free, portable version of the EVL and installed it on a personal computer. Figure 5 illustrates the diagram of the technological elements used in the educational intervention.

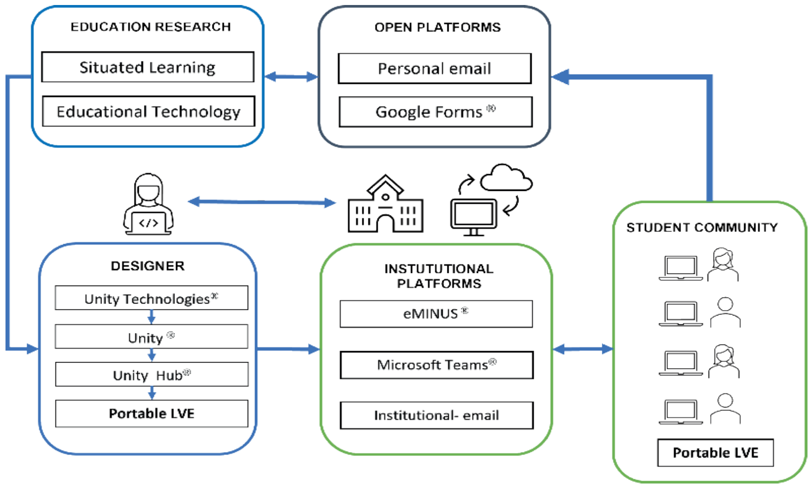

Figure 5. Architecture of the technological elements involved in the implementation of EVL.

Source: Own elaboration

5 I RESULTS ANALYSIS

Both a quantitative and qualitative analysis was developed to measure the effectiveness of the didactic proposal implemented through the Electromagnetism Virtual Laboratory, in order to evaluate several factors, such as the performance in the achievement of the fundamental concepts of electromagnetism, the students' perception of new didactic strategies involving virtual laboratories, and the motivation to use similar tools to the EVL in the future. A sample of 95 engineering students who used the EVL was polled by institutional means of communication for contingency reasons. The results obtained for each of the items to be evaluated are described below.

Learning performance. In the survey conducted, the students' performance was monitored via quizzes at the end of each simulation to monitor whether the learning of electromagnetism concepts was reinforced. In the survey conducted, the students' performance was monitored via quizzes at the end of each simulation to monitor whether the learning of electromagnetism concepts was reinforced. Several factors were analyzed: level of complexity of the quizzes, attempts to give answers, concept of electromagnetism involved, simulation mode related to the quiz question, the influence of the simulation directions, and perception of the virtual environment. Students' performance in each simulated experiment was analyzed based on the mentioned aspects. Table 1 summarizes the performance of the students in each practice, describing the percentage of students who answered correctly all the questions related to the theoretical concepts of electromagnetism.

Simulated exercise on EVL	Percentage of student who answer all questions correctly
1. Electric force	81.1%
2. Ohm´s law	52.6%
3.Coulomb´s law	85%
4.Faraday´s law	83.2%
5. fem applications	97%

Table 1

Performance assessment results after the application of the EVL.

It is observed that the practices that present a greater number of interactive elements, as in practice 5, provide better performance results. On the other hand, several difficulties were found in the performance evaluation of practice 2; such as more uncertainty in the graphical representation of the experiment, which resulted in higher difficulty for students in identifying the applications of Ohm's Law.

Students' perception of the virtual environment. In this research, the students' opinion regarding the experience with the EVL was analyzed, for which several questions with Likert scale were asked, referring to the use of the avatar, the interactive modality in the practices, the design of the virtual environment, the discussions after the practice, as well as the information on the scientific precursors of electromagnetism. The results indicate that the EVL had a generalized acceptance in each of the following sections (Figure 6).

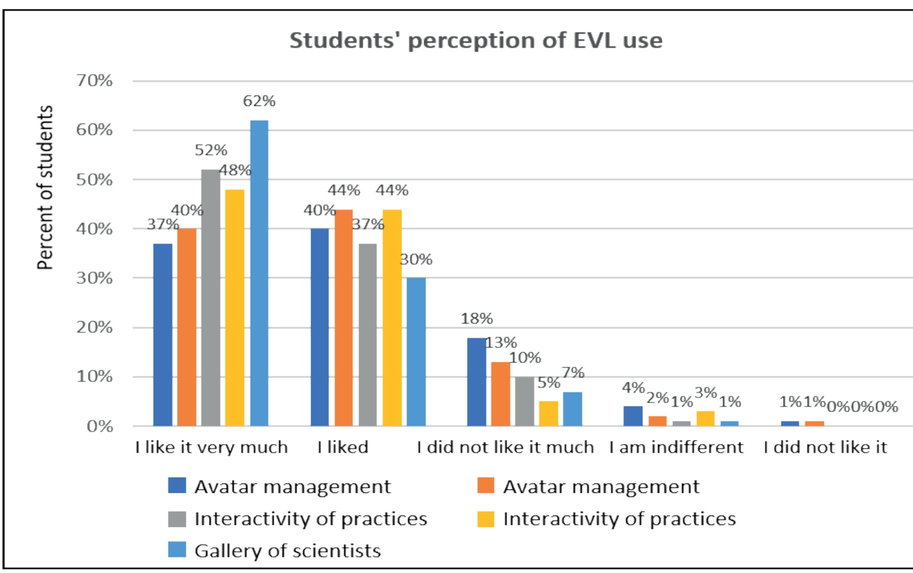

Figure 6. Surveyed students' perception of the use of EVL elements.

Source: Own elaboration.

Student perception of the usefulness of virtual environment. The EVL users were also asked about their perception of the usefulness they perceived in the use of the EVL as a complementary tool in the learning of electromagnetism concepts. The results are shown in Figure 7, in which it can be seen that most of the EVL users consider it as a useful didactic tool for the understanding of theoretical concepts and their applications.

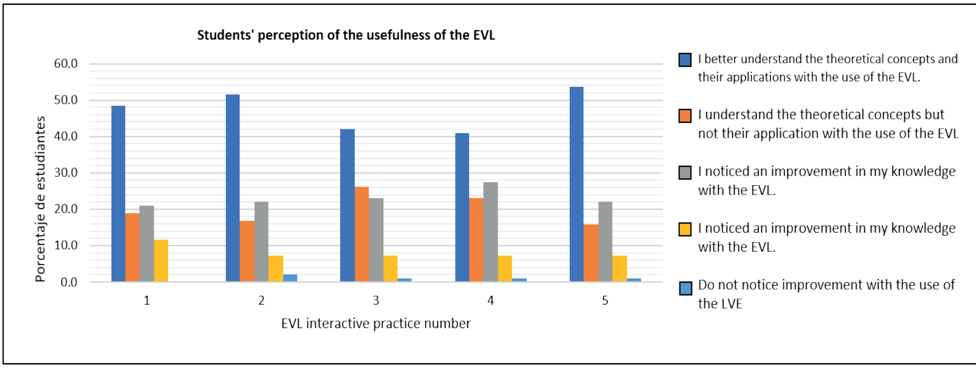

Figure 7. Students' perceptions of the usefulness of the EVL.

Source: Own elaboration.

Satisfaction Survey. A non-standardized satisfaction survey was conducted among students who used the EVL as a complement to their electromagnetics classes. The survey was conducted to quantitatively and qualitatively analyze the results of the EVL implementation and its impact on the FI student population. The survey consisted of 10 open-ended questions, as well as Likert, dichotomous and multiple-choice scales to determine aspects of satisfaction such as:

1. Level of satisfaction in the use of the EVL as a complementary tool to conventional laboratories.
2. Interest in the use of virtual laboratories.
3. Level of satisfaction in experimenting with each of the elements of the EVL.

    a. Navigation through the Avatar

    b. Virtual environment

    c. Gallery of scientists

    d. Practice simulation

    e. Quizzes

4. Interest in the use of virtual laboratories for learning.

5. Interest in participating in the development of virtual laboratories as didactic tools.

CONCLUSIONS

The use of virtual laboratories in engineering education has been a topic of growing interest in recent years. This study highlights the importance of situated learning as a teaching methodology for the development and use of virtual laboratories dedicated to areas of applied physics. The results show that students perceive these virtual environments as a useful interactive educational tool, suggesting that virtual laboratories are a viable and attractive alternative to physical laboratories.

Additionally, the study emphasizes the importance of a carefully considered instructional design to encourage student engagement in experimentation and learning. To achieve this, several aspects must be addressed, such as the level of immersion in the virtual environment, student participation in the interactive environment, simulation of professional engineering environments, and efficient problem solving inherent to the engineering field.

It is important to note that virtual laboratories must not only be visually attractive but also designed to facilitate the construction of knowledge and the relationship between the historical context, theoretical concepts, and practical applications of physics. Therefore, the instructional design of didactic strategies through immersive educational technologies must be a multidisciplinary and carefully considered process to ensure their effectiveness and widespread use in engineering education.

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