Design and Implementation of a Virtual Laboratory for Electromagnetics Teaching in Engineering

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Abstract

Virtual laboratories have had a special growth in recent years in which immersive education is attractive to students and enhances the teaching and learning processes in institutions of different educational levels. Although there are several types of virtual laboratories, there are important challenges for their design as a didactic strategy. One of the main difficulties is to have virtual educational environments especially dedicated to engineering areas, in which users can interact and be supported along their learning process. This paper presents the design and implementation of a Virtual Electromagnetism Laboratory as a didactic strategy considering situated learning approach for university engineering students. This paper presents the design and implementation of a Virtual Electromagnetism Laboratory as a didactic strategy under the situated learning approach for university engineering students. It describes the characteristics of the virtual environment, its design through free software, as well as the post-implementation analysis of the laboratory through the study of the perception of the university community.

Keywords

Virtual Laboratory, Electromagnetism, Engineering, Immersive education, situated learning.

1. Introduction

This article describes the research realized about the design and the implementation of an Electromagnetism Virtual Laboratory (EVL), applied to the learning process of fundamental concepts of electromagnetism at the higher education level. The article has the following structure by the following sections: 1) introduction and background, 2) case study, 3) EVL design, 4) educational intervention, 5) analysis of results, 6) proposals for future work and conclusions.

1.1. Virtual Laboratories

Virtual laboratories are used as affordable educational strategies, since they are designed so that the student can easily interact to a wide variety of integrated tools, allowing him/her to have enough time to complete the practices or simulations included and, at the same time, to repeat the exercises as many times as necessary to reaffirm the concepts under study. Currently there are several difficulties such as the level of immersion [1], the representation of contents [2] and the diversity of application areas [3], to make these tools efficient in the construction of abstract concepts that require a complex analysis and adequate guidance from the teachers.

1.2. Learning difficulties in Electromagnetism

Electromagnetism is a discipline of Physics that presents special difficulties for its learning [4] because it requires the understanding of abstract phenomena, which are difficult to perceive in a

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classroom or in a laboratory. Concepts such as electric force, electric field and electromagnetic field require diagrams and conceptual simulations in the teaching-learning process, usually represented by two-dimensional diagrams, through drawings on the blackboard or shown in textbooks. There are several graphical alternatives for teaching these concepts [5]. However, tools where interactive graphic simulations are presented make it possible to show in a more efficient way [6] the interaction of electric charges and the effect of electromagnetic fields, which are also interesting for students and extremely useful for teachers. However, most existing interactive applications do not have options such as in situ guided orientation, 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 do not include pre-practice and post-practice analysis. The guidance within the tool is useful for students to acquire meaningful learning by leading a process of metacognition that encourages 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 undergraduate engineering students at the Universidad Veracruzana (UV) in Mexico.

2. Case study

This research was conducted in the Orizaba-Córdoba region, in the Faculty of Engineering, Ixtaczoquitlán campus (FIcI) of the UV. One of the laboratories of the basic training area is the Physics Laboratory, which attends the four educational programs: Mechatronics Engineering, Civil Engineering, Industrial Engineering and Electrical Mechanical Engineering of the FIcI. Although there are adequate spaces for the experimentation of the basic concepts of electromagnetism, there are several additional difficulties that are identified at the time of performing the laboratory practices. In order to identify the FIcI students' perception of the practices in presential laboratories, and subsequently to have elements to compare them with the virtual laboratories, a Preliminary Diagnostic Survey (PDS) was performed. The PDS was done by digital means through Internet forms shared through the institutional accounts of a population of 104 students of the FIcI, in the academic period February - July 2020. This survey analyzed various indicators to establish the background and characteristics needed for the design of a Virtual Laboratory under the situated learning approach; that would attend the main issues of the student community, which were increased because of the contingency due to the COVID-19 pandemic, in accordance with what was found by [9]. In the PDS diagnostic survey, a series of questionnaires were conducted considering open questions, Likert scales, and dichotomous responses to identify quantitative and qualitative indicators such as: time spent online, method of internet access, devices they use for internet connection (PC, cell phone, tablet), weekly hours dedicated to study; digital media or educational tools that students use for autonomous learning, preference in teaching modality, knowledge and use of virtual laboratory. As well as, characteristics that students prefer in a virtual teaching session, limitations in performing practices in presential laboratories, availability of time for performing laboratory practices, access to specialized laboratory equipment, suggestions for teaching strategies involved in laboratory practices.

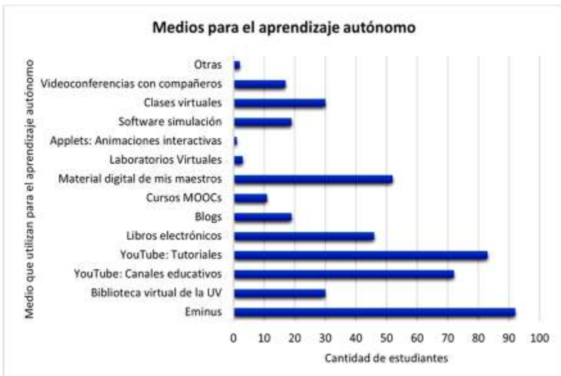

Figure 1. Source: EPD diagnostic survey, via Forms on independent study methods applied to students of the FIcI of the Universidad Veracruzana in May 2020.

It was observed that at FIcI, 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 You Tube 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 FIcI 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. Design of the Electromagnetism Virtual Laboratory

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

3.3. Guided interactivity

It was considered extremely important to display a module called gallery of scientists precursors of electromagnetism (Figure 3.a) 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.

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.

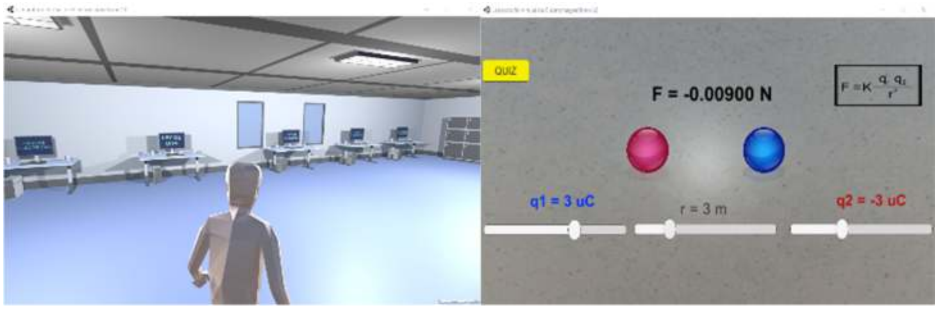

Figure 4. Example of laboratory practice environment in the EVL of the FIcI of the University of Veracruz.

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. 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.

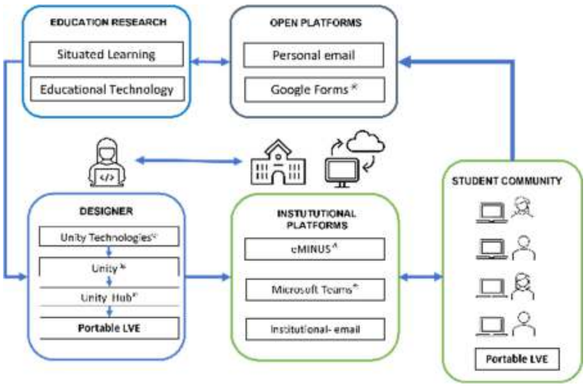

Figure 5. Architecture of the technological elements involved in the implementation of LVE.

5. 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 LVE 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.

Table 1
Performance assessment results after the application of the EVL.

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%

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 it was very important to identify the students' opinion regarding the experience with the LVE, so 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 post-practice discussions, as well as the information about the scientific precursors of electromagnetism. The results indicate that the EVL had a generalized acceptance in each of its sections (Table 2).

Table 2
Students' perception of the use of the EVL.

Simulated exercise on EVL	I liked a lot	I liked	It was not very pleased	It was indifferent	I did not like it
Avatar management	37%	40%	18%	4%	1%
Virtual environment	40%	44%	13%	2%	1%
Practice Interactivity	52%	37%	10%	1%	0%
Assessment quizzes	48%	44%	5%	3%	0%
Scientist information	62%	30%	7%	1%	0%

Most students found the experience with the EVL satisfactory. However, they also made suggestions to improve the avatar operation such as optimizing the keyboard controls for movement in the virtual campus navigation.

Students' motivation to use virtual laboratories. Finally, students were asked how they perceived the use of virtual laboratories as a didactic tool, as well as whether they would be interested in using them in the future to learn with this kind of learning strategies. The results are promising (Figure 6) in the case study, where even some of the engineering students reported that they would be interested in developing projects that use these kinds of educational virtual environments.

Figure 6. General perception of the surveyed students about their experience using the Virtual Electromagnetics Laboratory.

6. Future work

Some elements of the virtual environment that have areas of opportunity were identified through the satisfaction survey conducted after the application of the EVL. One of the aspects most suggested by the students is the customization of the avatar according to their personal preferences to make the virtual educational experience more pleasant, as well as the possibility of teamwork into the virtual environment. It is also intended to increase the number of practices and exercises with more interaction related to the concepts of electromagnetism application in engineering. Also, the available resources in other versions of Unity® will be considered.

7. Conclusions

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

The design of virtual environments dedicated to the area of engineering, involves several issues to apply them as a commonly tool in every institution. There are some aspects that are interesting research topics such as immersion level of the virtual environment, student participation in an interactive environment, educational strategies to closely simulate the professional engineering environments, how could the teachers design virtual laboratories to have students solve problems inherent to the area of engineering in an efficient manner. Therefore, the appropriate process of instructional design of didactic strategies through immersive educational technologies that involve multidisciplinary work in educational technology must be considered.

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