Impact of the use of virtual laboratories of electromagnetism in the development of competences in engineering students

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Abstract. This article summarizes a study whose objective was to determine the incidence of physical laboratory experiences in the development of competences interpretative, argumentative and propositive. Science allow students to interact with observable scientific phenomena, but often there are no experiences of electromagnetism in which a visualization of the interaction of charged particles with electric and/or magnetic fields is achieved due to the atomic level of these phenomena. Virtual lab experiences and computer-based visualizations allow students to interact with unobservable scientific concepts, allowing students to overcome the difficulties of connecting to real instances of the observed phenomenon. To involve students in our virtual electromagnetism laboratory, we implement multiple interactivity functions, including the exploration of 3D models and selected adaptive simulations. We use the Unity multiplatform videogame engine to generate a digital learning environment that offers a potential tool to improve the conceptualization of electromagnetism courses taught on campus and/or distance education courses. To obtain the results, a Saber-Pro style pre-test and post-test were carried out, which evaluated the competences established by Ministry of Nacional Education.

1. Introduction

Currently within the teaching of physics is very common to seek in the use of interactive media the development of some subjects, so as to facilitate their learning. The constant technological advances that drive the dynamics of today’s society, among which is the accelerated irruption in the latter of the Information and Communication Technologies (ICT), impose educational institutions, particularly those of higher education, the need to make transformations in their training processes, so that they respond to the training of future professionals who are prepared to give an adequate response to the current circumstances of the social environments where they operate. One of the most notable effects of the use of virtual simulators has been the change of vision of teachers toward the teaching of physics. The teacher assumes a role of facilitator and counselor, and understands that the student must be the protagonist of the process. Along these lines, the following functions of the professor can be mentioned in his new role: resource provider, organizer, tutor, researcher, facilitator [1]. The research carried out by Felder [2, 3, 4] in North American universities, Brazilian and other institutions of higher education show that intuitive, verbal, reflexive and sequential learning are achieved with traditional methods, but
disregard the visual, interactive and global learning. The research conducted by Kleinman and Dwyer [5] showed that there is a relationship between visual skills and learning levels achieved through the computer. Keller, et. Al. [6] conducted studies to determine the extent to which the 2D and 3D visualizations of phenomena favored the compression of concepts. His research showed that better results are achieved if conventional instruction is articulated with computer-assisted instruction. In order to facilitate the learning of electromagnetism, the group of professors responsible for the orientation of this course in the faculty of engineering of the Universidad del Magdalena working together with professors from the Universidad Industrial de Santander have developed a set of simulations in 2D and 3D of electromagnetic phenomena using the potential of the videogame engine of the Unity multiplatform platform to generate a digital learning environment that favors the conceptualization and comprehension of the electromagnetic phenomena of the students who take this course, and who allow it to interact with observable scientific phenomena, since there are often no experiences of electromagnetism in which a visualization of the interaction of charged particles with electric and / or magnetic fields is achieved due to the atomic level of these phenomena.

2. Advanced electrodynamics laboratories

2.1. Mass spectrometer

The simulation and visualization consists of three key regions, the first is the injection region on the x axis, it is a free region, that is, the beams do not interact with any force, once this region is overcome, the beam enters the region of crossed electric and magnetic fields to separate the ions of equal velocity (see section: Velocity selector), where the electric field is generated by two parallel metal plates separated by a distance of 6 cm, the magnetic field is produced by two Helmholtz coils (see Fig. 1). Finally, the ionic species of equal velocity can enter the third region and will be affected by a uniform magnetic field of magnitude \( B_0/2 \) with \( B_0 \) or the magnetic field of the selector. Three ionic species with elementary charge \( e = 1.6 \times 10^{-19} \text{C} \) and masses of 1, 2 and 3 UMA (unit of atomic mass) are simulated. The ions of mass 1 and 3 UMA are positive, the third ion is negative. This software is based on the numerical solution of the relativistic Newton-Lorentz motion equation under the Boris-Buneman scheme. Once the previous instructions are followed, a dialog box will appear in the terminal asking the user for voltage values between the plates and current in the coils. These values of potential difference and current will be given in volts and milli amperes respectively. When all the parameters are entered in the terminal, a visualization window that recreates the simulation will be generated, in which the path of the beam is evidenced when passing through the three previously mentioned regions. In the final region there is evidence of the separation of masses that initially arrive in "a single beam", printing the collision diameter of each species. The program also generates in the directory or folder containing the program, the files ((Ion + de1UMA.txt)), ((Ion-de2UMA.txt)) and ((Ion + de3UMA.txt)) that contains the information of the position in each axis for each moment of time, being possible to reconstruct the trajectory in an external plotter if the user wishes it.

2.2. Velocity Selector

The code simulates the dynamics of three electronic beams injected at three different speeds in the presence of an electric and a magnetic field, uniform and mutually perpendicular. The simulation and visualization consists of three key regions, the first is the injection region on the x axis, it is a free region, that is, the beam does not interact with any force, once this region is overcome, the beam enters the region of Crossed fields already mentioned, where the electric field is generated by two parallel metal plates separate a distance of 6 cm, the magnetic field is produced by two Helmholtz coils (see Fig. 2). The last region is again a free region where you can see the final deflection of each beam. One of the three beams is injected at a speed
Figure 1: (Color online) Dynamics of different ion beams injected at three different speeds in the presence of electric and magnetic fields.

exactly equal to the $E/B$ ratio and this is considered a reference beam because at this speed the electric field effect compensates for the magnetic field effect, resulting in a net force equal to zero. Another of the beams is injected at a speed $3E/B$ and finally the last at $0.7E/B$ called make fast and slow down respectively. This program is based on the numerical solution of the relativistic Newton-Lorentz motion equation under the Boris-Buneman scheme. Once the

Figure 2: (Color online) A velocity selector with a positively charged particle moving with velocity $v$ in the presence of a magnetic field directed out of the plane of the page and an uniform electric field vertically upward exists in the region.
previous instructions are followed, a dialog box will appear in the terminal asking the user for voltage values between the plates and current in the coils. These values of potential difference and current will be given in volts and amperes respectively. Once the requested information has been entered, the program can generate the simulation and its respective visualization. In the terminal information of the fields and the speed of the reference beam will be thrown. When all the parameters are entered in the terminal, a visualization window that recreates the simulation will be generated, in which the path of the beam is evidenced when passing through the three previously mentioned regions. The program also generates in the directory or folder containing the program, the files ((Fast electron.txt)), ((Slow electron.txt)) and ((Electron reference.txt)) that contain the position information in each axis for each instant of time, being possible to reconstruct the trajectory in an external plotter if the user wishes it.

2.3. Electromagnetic wave with discontinuity of medium

Figure 3: (Color online) The physical simulation contains two main but not independent parts: (1) the propagation of the wave in the free space this means that it propagates in the air and (2) the propagation in a medium of refractive index \( n \). No reflection occurs and wave energy is smoothly transferred to medium with refractive index. Note the absence of standing waves.

The present version of the software specifically allows to study the propagation of an electromagnetic wave in a region of space for each time step. The amplitude of the electric wave will be 30\( kV \) and its direction of propagation will be the positive \( x \) direction (see Fig. ). Then the code will request the refractive index \( n \) of the medium to which the electromagnetic wave affects, this value is not limited, but it is recommended to use values between 1 and 5. It is worth mentioning that the value of the refractive index can be less than 1, computationally this is possible and it means that the wave is going from a medium of higher refractive index to one of less, but physically this does not make sense since the speed of the wave in this medium less than 1 would be greater than the speed of light.

3. Pedagogical Results
The results shown in Fig. 4 correspond to the diagnostic test applied to 40 students, who took the course of electricity and magnetism offered by the engineering faculty of the Universidad del Magdalena, which was applied before the students used the virtual laboratories, in which the levels of learning and development of the competences, argumentative, interpretative and
propositive were evaluated. The analysis and tabulation of the results obtained were framed within the evaluation criteria stipulated by the Ministry of National Education. According to the results obtained in the tests applied to the students, at the beginning and at the end of the course, there is an improvement in performance in the interpretative, argumentative and propositional competences in group one (1) and group two (2) there is evidence of a better performance in the entrance test, in which it remains in the final test.

With the purpose of being able to show the acceptance of the use of Virtual Laboratories to generate significant learning and the development of competences in the students which study the subject electromagnetism, in groups 1 and 2 (see Fig. 5), a questionnaire of closed questions was chosen, formed by 16 items and an open question, to collect opinions outside the established questions. The items are written as statements in which we must indicate with a graduation from 1 to 5, all the possibilities of response, from the most contrary (1) to the most favorable (5). The possibility of not answering the affirmation is also included. A base survey [7] adapted to the context of this subject and the learning activity was used to select the questions. The questionnaire covers psycho-pedagogical aspects (items 1 to 4), didactic-curricular (items 5 to 8) and technical and functional (items 9 to 16). The internal consistency of the questionnaire was measured, analyzing the level of relationship between the 16 items that form it, for this purpose the Cronbach alpha index (α) [8] is calculated. We can consider that the questionnaire is reliable and the statistical results are valid, if the index α > 0.7. And the reliability of the internal consistency of the instrument can be estimated with Cronbach’s alpha. The measure of reliability using Cronbach’s alpha assumes that the items (measured on a Likert scale [9]) measure the same construct and are highly correlated [10]. The closer the value of alpha to 1
is, the greater is the internal consistency of the items analyzed. The reliability of the scale must always be obtained with the data of each sample to guarantee the reliable measurement of the construct in the specific research sample.

![Survey Acceptance of the Software Group 1](image1)
![Survey Acceptance of the Software Group 2](image2)

Figure 5: (Color online) The figures correspond to the results obtained from the acceptance survey, in relation to the phases of the questionnaire (psycho-pedagogical, didactic-curricular and technical-functional aspects), so much so that student’s opinion about their learning with the virtual laboratories, as well as the teachers who used them, having observed a greater affluence to the physics classes.

4. Conclusions
The development of applications that simulate laboratories of electromagnetism a tool with a future within the current technologies oriented towards new methods of teaching physics, among other reasons, for its ease of transmission through the web and its use in all systems operational, due to the implementation of simulations in Unity. Its incorporation into constructivist learning environments show excellent results in the study of electromagnetic phenomena, such as those achieved by students in the development of argumentative, propositive and interpretative competences. We develop seven additional simulations of electromagnetism in this research such as equipotential lines of electrostatic potential, particle in an electric field, particle in a magnetic field, electrostatic forces, magnetized disks, dispersion of positrons, acceleration with a cyclotron, each of them obtained a high acceptance according to the results achieved by the applied survey which showed approved students and higher marks.

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5. References
[1] García A and Gil M 2006 Revista Electrónica de Enseñanza de las Ciencias 5 304.
[2] Felder R 1988 Engr. Education 78 674.
[3] Felder R 1987 Engr. Education 77 222.
[4] Felder R and Spurlin J 2005 Int. J. Eng. Ed. 21 103.
[5] Kleinman E and Dwyer F 2016 International Journal of Instructional Media 26 53.
[6] Keller T, Gerjets P, Scheiter K and Garsoffky B 2004 Information Visualizations as Learning Tools 47 90.
[7] Morales E, García F, Barrón A and Gil A 2007 “Gestión de objetos de aprendizaje de calidad; caso de estudio” Actas del Congreso SPDECE.Oviedo.
[8] Morales P, Urosa B and Blanco A 2003 Construcción de escalas de actitudes tipo Likert. Una guía práctica. Madrid:La Muralla.
[9] Likert R 1932 Archives of Psychology 22 140.
[10] Welch S and Comer J 1988 “Quantitative Methods for Public Administration: Techniques And Applications” Editorial Books/Cole Publishing Co.