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Computational tool for learning electrostatic physics through the development of a disruptive methodology

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Abstract. A computational tool for learning electrostatic physics is presented through the development of a disruptive methodology. The tool allows the analysis of case studies based on Coulomb's law, Gauss's law, Poisson's equation, and Laplace's equation with boundary value. The tool was tested using reference exercises for each case study, making use of quantitative and qualitative comparative analysis between the traditional mathematical development and the computational tool. Errors were measured using Likert scale. The quantitative results showed errors of less than 1.8% in all the cases studied, concluding that the tool is effective. The qualitative results showed that the methodology allows a better development of the electrostatics learning process, dynamizing the study of complex topics such as electromagnetic physics theories through interactivity and technological resources, in addition to having a theoretical module developed using agile methodologies that provide dynamism and an intuitive environment to the interface.

1. Introduction

The study of electromagnetic theory has led to impressive scientific advances in recent years, such as: mirror fabrication techniques for telescopes [1], injection of photons into waveguide arrays [2], use of adaptive photodetectors to measure the focal length of a lens [3], influence of electromagnetic fields on the chicken egg [4], modeling of radiation/scattering problems [5], among others. Similarly, its teaching has been approached from different methodologies, especially with the use of technological tools; a virtual structure under the constructivist model allowed the creation of a video game that involved three fundamental elements of education: learning, evaluation, and practice [6].

The development of a virtual environment and remote laboratory could be an alternative to virtuality due to the constant isolation caused by COVID-19 [7]. The application of Kolb's learning styles in radiocommunication teaching achieved a transition from behaviorism to constructivism, presenting concept maps as the main tool [8]. And the use of didactics allowed to strengthen the learning of electromagnetic induction and the development of digital competences allowing to conclude, among other things, that information and communication technologies are potentially favorable for learning [9].

All branches of electromagnetic physics are rigorous and difficult to study; electrostatics is no exception; it is the branch of physics that analyzes the effects that occur between bodies due to their electric charges, *i.e.*, it studies electric charges in equilibrium [10]. This subject is of vital importance for the development of integral professionals and in view of the great challenges that have arisen in the academic field in recent years, it is necessary to innovate learning methods through the development of non-conventional methodologies.



Taking into account the above and knowing that it has been proven that technological tools improve academic performance by making teaching and learning processes more dynamic and efficient [11], a computational tool for learning electrostatic physics is presented through the development of a disruptive methodology.

2. Materials and methods

The methodology used in the research can be seen in Figure 1; this methodology is disruptive, does not follow a traditional procedure and was developed considering the agile methodologies Scrum [12] and Kanban [13].

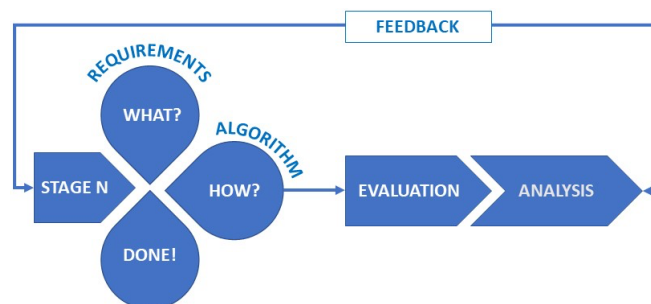


Figure 1. Software development methodology.

2.1. Requirements

Sources on electromagnetic theory [14-16] are consulted to know the topics addressed by different authors in electrostatics and their respective methodologies. Three topics are identified and chosen for the development of the investigation: (i) Coulomb's law, (ii) Gauss's law, (iii) Poisson's equation and Laplace's equation with boundary value.

2.2. Algorithm

The algorithm was changed several times according to the results of the evaluation and analysis processes; the final algorithm describing the behavior of the system is represented by the flowchart shown in Figure 2.

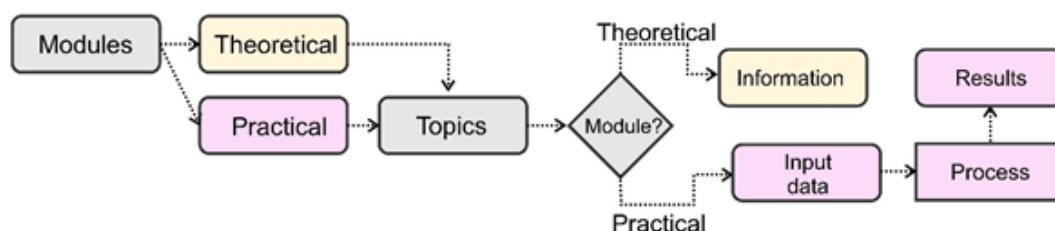


Figure 2. Flowchart.

2.3. Evaluation and analysis

The evaluation and analysis processes were developed considering the dynamic characteristics of agile methodologies with the purpose of obtaining a feedback process that modified each of the stages of the process. Ten stages were carried out until reaching the final product, which was represented in a graphic interface developed using a free programming language; this interface can be seen in Figure 3.

The interface is composed of two modules: a theoretical module and a practical module; the theoretical module contains all the necessary information, graphs, and equations according to the chosen topic of interest. The four topics are: Coulomb's law, Gauss's law, Poisson's equation, and Laplace's equation with boundary value. Likewise, in the practical module the subject to be developed is chosen and dynamic case studies are presented that allow changing variables, graphing fields, vectors and visualizing the results in real time.

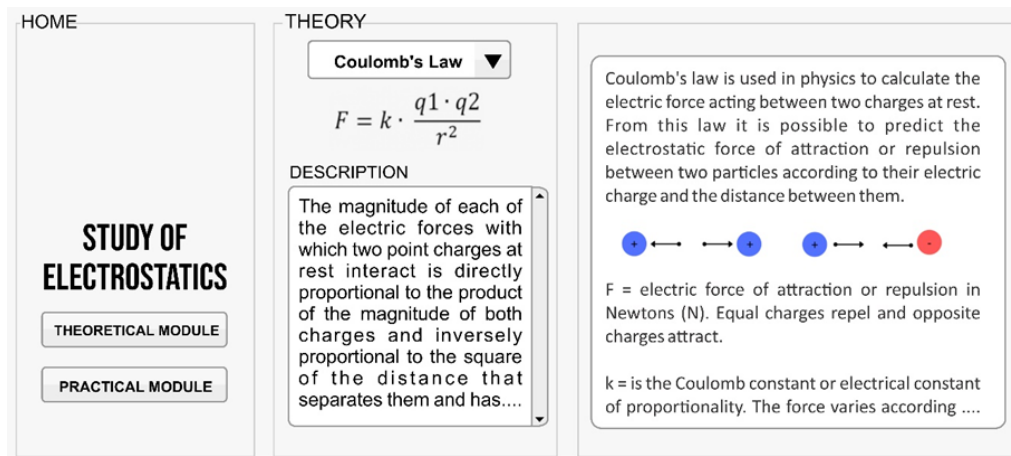


Figure 3. Interface developed.

3. Results and discussion

Several tests were performed on the tool to evaluate its performance on the different topics available. Case studies were chosen to be solved using the interface and through the traditional mathematical procedure in order to compare the results and perform quantitative and qualitative analysis.

3.1. Coulomb's law

Figure 4 shows one of the classic case studies present in the books consulted and which was analyzed both mathematically and with the computational tool; two-point charges are suspended at a common point by two wires of negligible mass and a given length. We are asked to demonstrate the equilibrium and the angle of inclination of each wire with respect to the vertical axis.

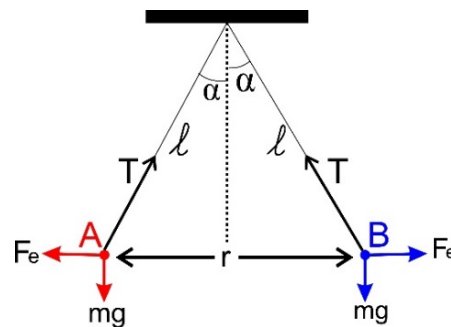


Figure 4. Case study, Coulomb's law.

3.2. Gauss's law

Figure 5 shows the case studies that were developed in relation to Gauss's law. Figure 5(a) shows the case study of point charges, Figure 5(b) shows the case study of linear charges and Figure 5(c) shows the case study of uniformly charged spheres.

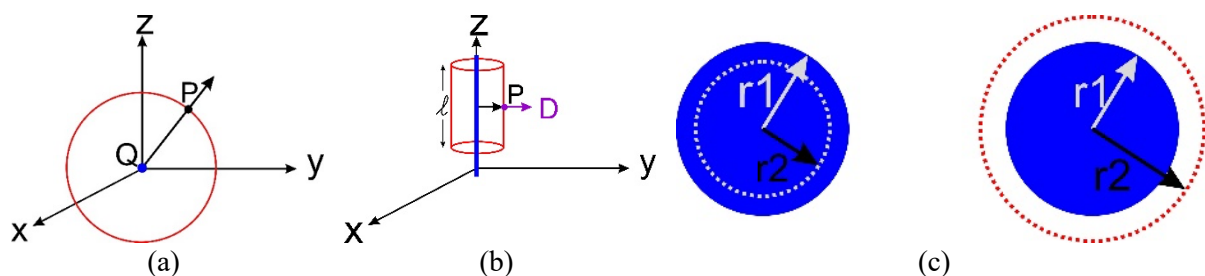


Figure 5. Case studies, Gauss's law; (a) point load; (b) line loading; (c) uniformly charged sphere.

3.3. Poisson's equation and Laplace's equation with value at the boundary

One of the most representative case studies of Poisson's equation and Laplace's equation that were analyzed in the development of this research was that of an electrohydrodynamic pump. The high-voltage current-carrying components must be cooled to remove the heat caused by ohmic losses. One form of pumping uses charges from an electric field to transmit force to the cooling fluid. The region between the electrodes contains uniform charge that is generated at the left electrode and accumulates at the right electrode. It is usually requested to calculate the pressure in the pump. The graph of this exercise is shown in Figure 6.

The quantitative analysis was performed by calculating the average error for all the case studies of each subject and was complemented with a Likert scale [17], as shown in Table 1; the Likert scale consisted of evaluating the efficiency of the tool in comparison with the traditional mathematical procedure on the basis that an error of less than 1% is equivalent to a very efficient performance, an error between 1% and less than 3% is equivalent to an efficient performance, between 3% and 5% is equivalent to a regular performance, and for errors greater than 5% the performance is deficient. It is worth mentioning that in all the case studies analyzed there were no results with regular or poor performance.

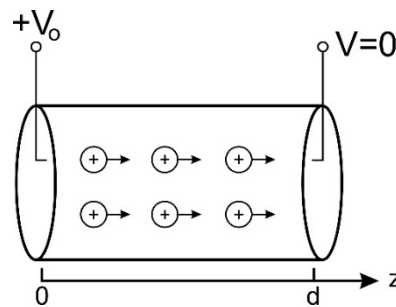


Figure 6. Case study, Poisson's equation, and Laplace's equation.

Table 1. Quantitative analysis of the case studies.

Thematic	Error (%)	Likert scale
Coulomb's law	1.34	Efficient
Gauss's law	0.65	Very efficient
Poisson's equation and Laplace's equation	1.75	Efficient

4. Conclusions

The development of a non-conventional methodology with a computational approach for the study of electrostatic physics added dynamism to the teaching and learning process. The use of a disruptive methodology breaks with conventional paradigms, allowing the advancement of academic processes in the teaching of electrostatic physics by making use of technology to optimize the development of knowledge.

The average errors were all less than 1.8%, from which it can be inferred that the tool is efficient and that it allows to carry out case study analysis of electrostatic related topics.

By having a theoretical module, the interface promises to be an effective tool in the academic process of teaching electrostatics, based on the premise that in a single source the student will have the possibility of acquiring knowledge and putting it into practice.

The interactivity of the interface encourages the learning of electrostatics by adding dynamism to the analysis procedure, considering that in electromagnetic theory these processes are usually tedious leading to the desertion of many students, however the use of technology and specifically of the graphic interface, is presented as an alternative for the solution of this problem. Research on the impact of computational tools on physics learning is suggested by conducting analyses with samples of students from different academic grades.

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