Teaching Electromagnetics in an Electrical/Electronic Engineering undergraduate course: the hybrid option

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***Abstract*—Effective teaching and learning of a number of topics in Electrical and Electronic Engineering undergraduate programs is not easy to accomplish due to the efforts to understand complex mathematical equations and complicated interactions that are difficult to visualize. The traditional "chalk and talk" teaching method is no longer effective. This method that has been used for hundreds of years is providing ineffective results, especially when it involves "topics that demand 2D or 3D visualizations, such as propagation of electromagnetic fields, antenna patterns and waveguides. This paper aims to show some new teaching processes perspectives for subjects encountered in Electrical and Electronic Engineering courses. It presents advantages and experiences between the UoN - University of Nottingham (United Kingdom) and the IFSC –Instituto Federal de Santa Catarina / Federal Institute of Santa Catarina (Brasil) in teaching topics regarding Electromagnetics, by using a variety of simulation and visualization approaches**

Keywords—engineering education; hybrid teaching processes, electromagnetics

I. Introduction

Nowadays, the new generation attending school is one that was already born in the digital technology world of gaming and smartphones. Thus, it is likely that educational theories and current teaching methods that have been developed years ago no longer correspond to the way young people think and learn today. Still, it is becoming clear that one of the reasons why teachers are not successful in their students' education is the fact that they are working hard to educate a new generation with old media, making use of tools which are no longer effective [1]. This is because this new generation of students, known as the Z Generation [2], which includes those born in the mid-80 or -90 [3], are zapping, that is why they are called the Z generation. Young people today change from one channel to another on television; go from the internet to the cell phone; from the cell phone to the video and return to the internet again. In most cases, they never conceived the planet without a computer or a smartphone. Their way of thinking was influenced from birth by the complex and fast-moving world that engendered technology. A world that has no geographical boundaries as for them, globalization is not a value acquired through life at a high cost.

They learned to live with it in childhood. While others seek to acquire information, the challenge facing the Generation Z is otherwise. They need to learn how to select and separate information. Reference [2] highlights the need for a new teaching methodology that encompasses the technologies used by the students: "Our students have changed radically. Today's students are no longer the same kind of people for whom our educational system was developed" [2]. Thus, 'traditional' classes limited to the board and chalk do not motivate students anymore. Reference [4] adds that "Students around the world are resisting the old "telling" paradigm with all their might. When their teachers lecture they just put their heads down, text their friends, and, in general, stop listening". On the other hand, classes mediated by new technologies have the power to connect students with the outside world, besides facilitating and mediating learning [5]. New technologies, such as, software, virtual learning environments, remote laboratories, digital whiteboards, tablets, laptops, and smartphones are examples of tools that are part of what we call today New Digital Technologies of Information and Communication (NTDICs). Moreover, when used in the classroom mediating the process of teaching and learning, and the teacher-student interaction, cause positive effects and can be used as a way to effective learning and quality, as several studies have demonstrated [5] [6] [7].

It is necessary to analyze consciously and critically, not only the initiative and the implementation of new technologies, but also their daily practice. Does their use really lead to a transformative education? [8]. For this reason, only investment in equipment/software, but not in the training of professionals to use NTDICs is not a synonym for improvement or change [8]. NDTICs can cause an immeasurable impact on education when used as tools to promote communication and to enhance the teaching-learning process. To achieve so, a constant movement of reflections, questions, and discussions is necessary [9]. In addition, NDTICs can be applied in order to expand both space and time in the classroom because they eradicate the concept of located and temporal teaching and learning [10]. This is to say that we are moving towards a new

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period of "convergence and integration of media: everything starts to integrate with everything, talking to everyone and everything. Everything can be published in any media. Everybody can be producers and consumers of information. The digitization brings the multiplication of choice possibilities of interaction. Mobility and virtualization release us from rigid, predictable and certain spaces and times. The physical world is reproduced in digital platforms [...]. There is a growing, very new and rich dialogue between the physical world and the so-called digital world with its many research activities, leisure, relationship [...] that profoundly impact the education and ways of teaching and learning that we used." [10].

However, it is necessary to strengthen that the use of technology in education, whether in the classroom or outside it, as in distance education or in blended learning formats of education, requires a specific plan that defines the didactic aspects required for proper hybridization of pedagogical practice. Hybridizing education refers to the approximation of the NDTICs in face-to-face classes, using them "as mediators in the process of knowledge construction." [11]. Proper integration of NDTICs in the educational processes takes place when the teacher uses various resources from these technologies with clear educational objectives that provide reframing of their practice and student learning. In education, the NTDICs have the potential to fortify teaching work since they can involve reflection and deepening of certain "didactic aspects, which gain new meanings, dimensions, and characteristics" [9]. Teachers from different areas of knowledge must be open to new ways of human knowledge, new ways to raise and "master the knowledge, new ways of production and teaching-practice knowledge appropriation in order not to be stagnant in teaching methods and theories of obsolete work" [6]. Reference [6] also recognize the potential of the NDTICs in the teaching-learning processes. Through them, a new look at teaching can be promoted, especially from the moment that the challenge of teacher training goes beyond the traditional "chalk and talk" method of teaching. Reference [12] argues, however, that the NDTICs are not primarily responsible for a successful mediation between education and technology. According to her, it is necessary that teachers are "aware that their competent professional action will not be replaced by technology. Instead, they expand their field of knowledge far beyond the classical school [12]. Hence, it seems impossible not to agree with the fact that the NDTICs have the potential to transform the current educational system, expanding the school dimensions and enabling dynamic, collaborative, innovative, and interactive teaching practices, [12], leading then, to a genuine hybrid education process.

In this paper, the experience of teaching 2nd year Electromagnetics subjects at the Instituto Federal de Santa Catarina (IFSC), in Brazil and the 3rd year Microwave Communication module at Nottingham University (UoN), in the UK, with a combined use of analytical, numerical, and visualization tools is presented.

II. Simulation Techniques to Teach Electromagnetics Related Topics

Around the world, many initiatives encourage lecturers, teachers, and professors to use innovative methods in the classes of several knowledge areas. Specifically, in the Electrical and Electronic related topics, we can find some good experiences that give better results to our "new students", the digital natives, from the Z generation onwards, who have strong characteristics of being multimedia, multicultural and easy-use of technologies [7], [11]. Teaching Electromagnetics is a special task in the Electrical and Electronic Engineering teacher´s life. The topics discussed here, have a strong mathematical dependence. Hence, students need to be very prepared in that matter. Additionally, even if the student has all the pre-requirements to attend this kind of discipline, the spatial visualization needs to be part of the learning process. Subsections A and B show two experiences.

A. The Experience at Instituto Federal de Santa Catarina

There are some new initiatives at IFSC, in the Electronic Engineering Program that were implemented in 2015, specifically to teach the following subjects: Electromagnetics and Antennas Principles. A program was developed for the teaching of these subjects, and it allows the interaction with a graphical interface to change parameters of several electromagnetic problems, giving to each student the visual perception of the electrical quantities. The classes are organized in groups up to 16 students where each student has a specific task, supported by traditional lectures. They are based on problems and on conventional experiences.

The software has the option of 2D or 3D visualization and it can also generate GIFs (Graphics Interchange Format) to show the time-domain behavior of these electromagnetic problems. The program can simulate problems of Electrostatics, Magnetostatics, and Electromagnetic Waves. Starting with a simple concept of vector calculus, learning is enhanced by introduction of two-dimensional (2D) and three-dimensional (3D) visualization tool. This is also extended to the analysis of equipotential lines and gradient calculus for different functions. For more complicated problems, numerical algorithms based on the Finite Difference Time Domain (FDTD) method [13] and Finite Element Method (FEM) [14] are used to help understand and visualize the electromagnetic concepts. For example, 2D and 3D visualization is used to understand forces and fields between charges, as shown in Figure 1. Furthermore, the software was deployed to understand the potential analysis between metallic surfaces, as well as in capacitors. In Magnetostatics, the FEM method is used to enhance learning by visualizing the field produced by currents in wires and, also, the simulation of magnetic circuits. As shown in Figure 2, it can be seen that the magnetic field generated by the currents in the coil is concentrated into the magnetic material and spread through the gaps. For the analysis of the electromagnetic wave propagation, the numerical tools are used to simulate and analyze the reflections of a plane wave, in different media. The FDTD method is used for simulations mainly in 2D, which allows the analysis of different wave scattering scenarios and simplified antennas. The most interesting is the observation of the waves propagating in time domain and interacting with the nearby obstacles, as shown in Figure 3, where a point source is used to excite a wave at the left-bottom corner. The electromagnetic waves propagate through the scenario, reflecting on the metal plates and the central block. Also, 2D FDTD is used to visualize the electromagnetic wave propagation of a dipole antenna, as shown in Figure 4. The GIF format is used to visualize the propagation of the standing wave in the metal waveguide and its radiation by the horn antenna, as shown in Figure 5.

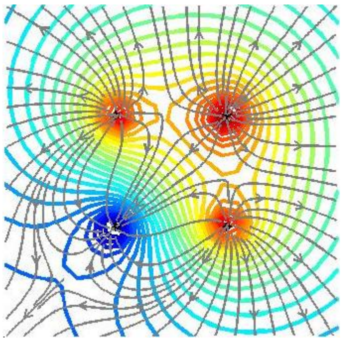


Fig. 1. Visualization of the electric field lines and potential lines due to 4 charges. The vector forces between them are also possible to see.

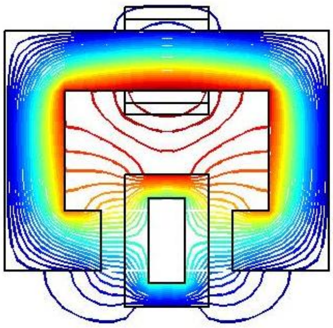


Fig. 2. Simulation of a magnetic shield in Magnetostatics.

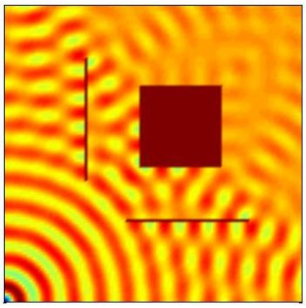


Fig. 3. Electromagnetic wave scattering between metal devices.

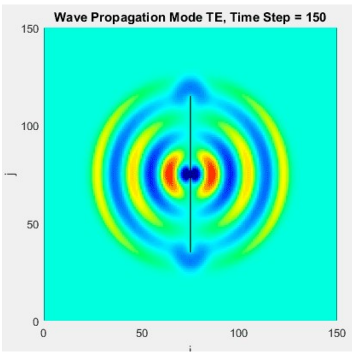


Fig. 4. Visualization of the electromagnetic wave propagation of a dipole antenna.

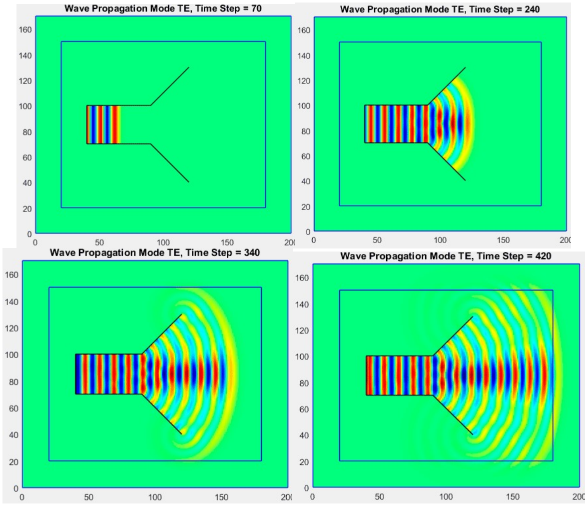


Fig. 5. Steps of a GIF file generated by the program for the wave propagation in a rectangular horn antenna.

B. The Experience at University of Nottingham

The University of Nottingham (UoN) has one of the most productive Institutes in the simulation of Electromagnetics problems. Having developed the transmission line modelling method (TLM), the George Green Institute for Electromagnetics Research (GGIEMR) is an international center of expertise in this area. In the website of the GGIEMR (https://github.com/ggiemr/ggi_tlm) it is possible to find a free sample of the open source software (ggiTLM), which was developed to simulate electromagnetic problems and it is now been used for research purposes.

The third year module “Microwave Communications” at the UoN has been recently re-structured to include more hands-on learning and practical design examples. The main topics in this module are transmission line analysis, metal waveguides, antennas, and antenna arrays. Traditionally taught, the module has seen a rapid decline in student’s interests especially in the area of transmission line analysis and understanding of fundamental principles of metal waveguides. This was hardly surprising, as the students could not make a connection between the theoretical material and the real engineering problems. To re-invigorate the subject, a more radical approach is used whereby the traditional style lectures are deployed but the module assessment is carried out through three different types of coursework. Each coursework covered a particular topic, but the tasks were extended to the design aspects of particular microwave components. By doing so, the learning process is enhanced and strengthened and the relevance of taught material becomes more obvious to a student. For example, transmission line concepts were covered by learning how to design a 4GHz lowpass stepped-index microstrip filter where transformation between lumped and distributed components is easy to understand. Moreover, the students also learned that there are three stages in microwave filter design, starting from the lowpass prototype, mapping inductances and capacitances to transmission line equivalent circuit, as shown in Figure 6, and, finally, mapping transmission lines to a realistic microstrip line [15]. The design and analysis is done using ADS – Advanced Design System software [16].

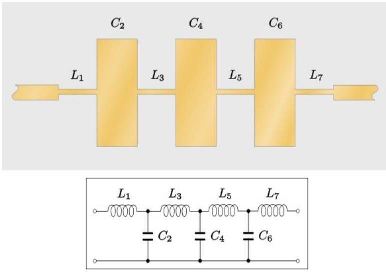
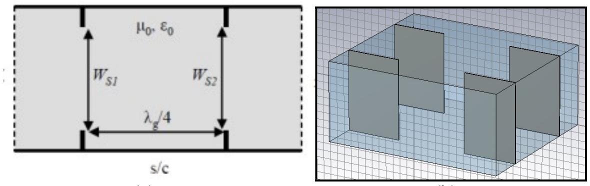


Fig. 6. Stepped impedance low pass filter using the ladder topology

Topic of metal waveguides is re-enforced by a waveguide bandpass filter design. For this purpose, a free version of the student edition of the CST (Computer Simulation Technology) software is used (https://www.cst.com/academia/student-edition). The students are first asked to analyze a WR90 waveguide, which includes understanding cutoff frequencies and modal profiles of different waveguide modes. The term 'WR' stands for 'Waveguide Rectangular' and the number with it indicates the waveguide dimensions inner width in hundredths of an inch. For this task, they are asked to compare analytical values of different mode cut-off frequencies with the numerical ones, in order to understand the concepts of convergence with the mesh size and results accuracy.

Design aspects are taken from a simplified 2D waveguide analysis and understanding the approximations made in reducing the full 3D geometry to 2D, as shown in Figure 7. The student then optimizes the filter performance by correcting the dimension of the iris posts.



(a) (b)

Fig. 7. Comparing results obtained between the a) 2D and b|) full 3D waveguide geometry.

For the third exercise, the students design a microstrip patch antenna operating at 12.5GHz and having a bandwidth of 2GHz using the CST software. The students learn how to design patch antenna by combining analytical approach of [17] with the full 3D implementation in the CST software. Quarter wavelength transformer is used for matching purposes and, also to re-enforce the importance of impedance matching techniques. It is important to note that analytical approach will not lead perfect answer and that students need to recognize that approximation made in the design stage result in inaccuracies in the actual design, for example shifting of the antenna center frequency. Students, then, learn how different antenna parameters affect antenna performance and undertake a process of optimization of the antenna performance, as shown by optimized S11 parameter and radiation profile in Figure 8. The S-parameters describe the input-output relationship between ports (or terminals) in an electrical system. In practice, the most commonly quoted parameter in regards to antennas is S11. The S11 parameter represents how much power is reflected from the antenna, and hence is known as the reflection coefficient (sometimes written as return loss. Besides, software also enables them to look at the field patterns of the antenna, as shown in Figure 9, as well as the planar and spatial radiation patterns. Student-centered learning was encouraged by provision of brief ADS and CST manuals. Students work independently on their coursework and the support was provided through timetabled tutorial sessions lasting 2 hours per week.

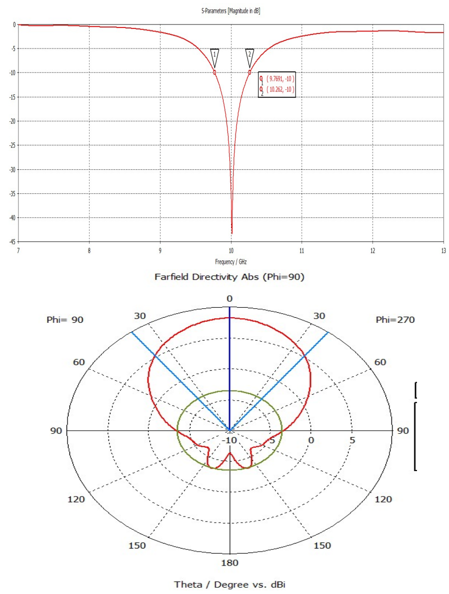
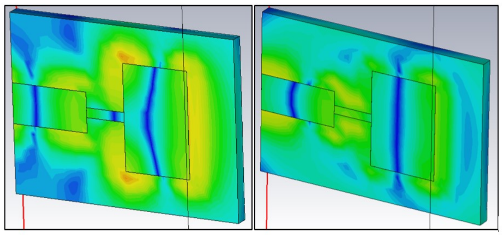


Fig. 8. S11 of the antenna and antenna radiation pattern.



(a) (b)

Fig. 9. Absolute value of the electric field at the a) front and b) back of the antenna.

The learning process was enhanced by computer lab sessions on which they could ask module convener questions and discuss their results. By writing their results in the form of a report, they also practiced and learned how to critically discuss and analyze results.

C. Other Experiences - Remote Laboratories

According to [18], "Remote labs stand for physical apparatus connected to computer-controlled instruments able to be remotely accessed for carrying out real-world experiments. This definition leads to the expression "remote experimentation" which denotes the type of experiments that can be done in remote labs, in opposition to "virtual experiments", or "simulations", which can be done in "virtual labs". For a complete understanding, hands-on labs refer to physical spaces where users perform experiments by directly manipulating the instruments and/or apparatus under experimentation. The more recent expression "hybrid labs" refers to a sort of environment where parts of the apparatus under experimentation and/or the instruments connected to those apparatus are real, and other parts are modeled, i.e., correspond to mathematical and data models running on a computer. These two parts, together with some traditional lectures, interact during the course of the experiment, hence the word "hybrid".

A remote experimentation is a real kind of practical experiment, where all non-idealities of a real problem are presented. The power, the signals, and the measurements are all provided from real equipment. The difference is that the students remotely connect the components of the experiment and operate the instruments from a computer in a different place where the remote lab is installed.

This educational method is not exclusive for the Electrical and Electronic area. There are many remote labs operating in several educational institutions [19].

III. Discussions and Measurement Methods

Simulation software/programs, remote labs, virtual labs or hybrid labs? Measuring the efficiency of the teaching methods listed above is not easy to accomplish.

The most popular instruments to measure teaching methods efficiency are tests, questionnaires and interviews. Combining them altogether would probably be an effective alternative way to evaluate students' learning progress. At the same time, this combination can be revealing because it will enable the teacher/researcher to find out whether or not the students enjoy the new teaching methods.

In the near future, this paper's authors intend to apply a combination of the aforementioned methods at the Electromagnetics (and related topics) in the Electrical and Electronic Engineering undergraduate programs of the University of Nottingham and Instituto Federal de Santa Catarina. In order to verify the efficiency of these methods, two questionnaires should be applied to students/participants: (a) the first, should be applied before the beginning of the classes, containing questions regarding what students expect from the specific course and how comfortable they feel using new educational techniques. At that moment, a brief explanation about the available methods has to be offered and (b) the second, should be applied after the end of the classes, containing questions concerning "if and how" the new methods improved their learning. Semi-structured interviews along the experiment should be applied to some students chosen at random to verify if the partial objectives have been achieved.

All data obtained before, during, and after the classes will be compiled and triangulated. Results will be analysed qualitatively and quantitatively and will be discussed in light of existing theories [1] [2] [4] [12], among others, and research studies on NTDICs applied to higher education.

IV. Conclusions

The hypothesis sustained in this paper is that new digital information and communication technologies together with traditional lectures and interaction, i. e., the hybrid option, will strongly affect Electromagnetics teaching-learning process through a variety of simulation and visualization approaches and, also, hands-on or remote laboratories. It is believed that this methodology can be motivating and, an effective and attractive way to teach and learn Electromagnetics.

The British and the Brazilian examples mentioned in this article reveal that the new/modern teaching approaches can be more successful than the old and traditional ones and can bring better results for the new students' generation.

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