APPLYING ACTIVE LEARNING IN THE ELECTROMAGNETISM CLASS: A FIVE-YEAR ASSESSMENT

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ABSTRACT

The intrinsic difficulty of studying electromagnetism added to the ignorance of its implications and applications in our daily life has reduced the number of students who would probably work in this area at the end of their careers. Although it is an opportunity for them to learn and strengthen their professional profile, students usually perceive the electromagnetism class only as a degree requirement. To increase the interest of students in the study of electromagnetism and the utility value of its applications, as well as to improve the general perception and positive attitude of students towards this course, we have implemented and tested an active learning approach (Project-based learning –PBL-) since 2014. These changes were motivated by the adoption of a new CDIO-based curriculum in the electronic engineering program at the Javeriana University in Colombia. The purpose of this article is to illustrate the results obtained by five years of direct and indirect evaluation of students in electromagnetism classes, in terms of their learning graduality of key topics in the field, difficulty perception about learning them, and the general perception of the class. This evaluation was conducted over five years, comparing two different class sections each semester. A class section adopted PBL and active learning within the CDIO framework and the other section (which functioned as a control group) was taught using traditional methodology. In the class section taught with PBL and active learning, the results showed significant improvements in the general perception of the Electromagnetism class, in the learning of complex subjects, and the knowledge of the applications of electromagnetism. Likewise, the results show an increase in the interest of students to get involved in more projects related to electromagnetism later in their undergraduate studies.

KEYWORDS

Electromagnetism, Active learning, PBL, CDIO, Standards: 7, 8, 11.

INTRODUCTION

In recent years there has been a great increase in the demand for wireless technologies and this demand will continue to be sustained for a long time, not only due to the rise and implementation of 5G networks but also new paradigms the Internet of Things (IoT). This growth in demand increases the need for engineers with knowledge in all topics related with wireless communications, unfortunately, the perception of undergraduate students regarding these topics is that it is problematic and complicated. In fact, this has also been a case study of some authors like Sadiku (1986), Rosenbaum et al (1990), or Keltikangas et al (2010), and additionally the students do not find a relation to Maxwell's theoretical work nor do they visualize its application in wireless technologies, which requires that alternatives be created (Lim, 2014). These problems ask for a new teaching that not only motivates students to learn about these topics but also facilitates the appropriation of concepts and their applications.

These difficulties mentioned have impacted both students and teachers since the last decade. One example to illustrate this impact is that the number of conferences related with electromagnetism related topics has decreased, (MIT, 2019), (Berkely, 2019), (Stanford, 2019), which goes against technological trends and the need for engineers with effective knowledge and the ability to develop novel solutions in the field of electromagnetism and wireless communications. These fields, by nature, are a dynamic development area (Rosenbaum et al, 1990).

Electromagnetic theory topics and courses are part of the study plans of several universities in the world (Collier, 2017), (Sadiku, 2018), (Lim, 2014), (Lumori et al, 2010). Some of these courses have been approached with variations in their contents, reducing the depth of these and even with different perspectives, to try to solve the difficulties that students face (Lim, 2014), (Lumori et al, 2010). Innovations have been made using three-dimensional models (Huk, 2006), interactive learning environments such as Visual Electromagnetics (VEM) (Miller, E, et al, 1990), use of numerical approaches (Hoole, S et al, 1993), Computational Electromagnetism (CEM) (Trlep et al, 2006), Computer-aided instruction (CAI) (Vidal et al, 1997), (Crawley et al, 2014), incorporating applied software such as Matlab (Bertolo, J, et al, 2002), texts and experimental platforms with interactive multimedia interfaces (Liu et al, 2018) and even project-based learning (PBL) (Prince, 2004), (Jonassen, 2014), (Prince et al, 2006), (Spikol et al, 2018), which has shown an improvement in academic results (Macías-Guarasa et al, 2006). Our traditional course methodology has used some of these ideas, but the one we propose has had modifications that have been adapted to our own context, for example PBL.

One of the characteristics in the programs under the CDIO framework is the integration of learning experiences that lead to the acquisition of disciplinary knowledge and skills (CDIO), in our case, we use PBL and active learning [28], which involves students as active participants in their learning process (Bravo et al, 2016), (Crawley et al, 2014). So in this document we describe and analyze the implementation of an undergraduate course in electromagnetism under the CDIO framework with special emphasis on standard 8 (Active Learning), using group work experiences through projects focused on improving the concepts and their application over five years. The topics that we address in this document are the description of the electromagnetism course and its context, later the projects proposed under the CDIO framework, and the results obtained by the students will be described, then the analysis of the collected data will be done, quantitative and qualitative, finally the results obtained and future job prospects will be shown.

COURSE DESCRIPTION

The course is Electromagnetic Transmission. It is in the third year of the Electronic Engineering undergraduate program, which has three contact hours per week, for 16 weeks, and is offered each semester. The study plan divided by weeks can be seen in Table 1.

Traditionally, the methodology used in this course is based on theoretical lessons, with mathematical examples and exercises to do at home, the size of the groups does not exceed 30 people and usually, four to five groups are offered (at different times) in the year.

Given this situation of having different groups, in each semester there was a control group (traditional methodology) and one or two groups, with the methodological proposal presented in this document, which aims to integrate learning experiences in such a way that they facilitate the acquisition of lasting knowledge (basic concepts), using the project-based approach, as an active learning tool in which students are highly involved in their learning process. It is worth to note that although the course is project-based, it includes theoretical lessons oriented towards the development of the projects.

Table 1. Syllabus of the Project-Based Electromagnetic transmission course

Topic	Hours
1.1 Multivariable calculus and complex analysis review Course content description, a brief review of the theory of complex variable functions, an overview of multivariable calculus: orthonormal coordinate systems, vector differential and integral operators, vector and scalar fields properties (Sadiku, 2018), (Cheng, 1993).	3
1.2 Electrodynamics Review of the static Maxwell's equations, dynamics and Maxwell's vision, general boundary conditions, energy storage, power dissipation, transport and power guidance, radiation and introduction to fundamental propagation phenomena (reflection, transmission, scattering, and diffraction) (Jin, 2015), (Balanis, 2012), (Orfanidis, 2016).	9
2.1 Electromagnetic wave's propagation in absence of sources Mathematical foundations of electromagnetic wave propagation from the Newtonian perspective of waves propagating in mechanical media. Helmholtz equation and solution for plane waves (Jin, 2015), (Balanis, 2012), (Orfanidis, 2016).	3
2.2 Electromagnetic wave's characteristics Waves polarization, power density, group and phase velocity, phase distortion. Propagation in dispersive media, distortion effects (Jin, 2015), (Balanis, 2012), (Orfanidis, 2016).	3
2.3 Electromagnetic wave's reflection and refraction Reflection and refraction of electromagnetic waves in different media, normal and oblique incidence, Snell's law, and phase matching. Propagation in multiple media. Design example of antenna radome with the Smith chart (Jin, 2015), (Orfanidis, 2016).	3
2.4 Electromagnetic wave's diffraction Doppler effect, scattering, and simplified models of diffraction (Balanis, 2016),.	3
3.1 Electromagnetic wave's propagation in presence of sources Vector potentials formulation, the extinction surface equivalence theorem. Wire and rectangular aperture radiation (Jin, 2015).	3
3.2 Antenna's parameters Antenna's definition and parameters: gain, directivity, radiation pattern, radiated field, effective area effective height, polarization, bandwidth, antenna matching (Balanis, 2016).	3
3.3 Antennas case studies Rectangular horn antenna, infinitesimal and Hertzian dipole (Balanis, 2016).	3
4.1 Computational Electromagnetics (CEM) - Frequency methods Introduction to fundamentals of computational electromagnetics methods, microwave, and RF systems applications. Frequency methods in 1D: Method of Moments (MoM), Finite Element Method (FEM) (Jin, 2014), (Balanis, 2016).	3
4.2 Computational Electromagnetics (CEM) - MoM simulation An MoM algorithm for a wire antenna simulation, electric current distribution, and far-field calculation (Gibson, 2021), (Harrington, 1993).	6
4.3 Computational Electromagnetics (CEM) - Time methods Time methods in 1D and 2D: Finite Difference Time Domain Method (FDTD) in pulse-based techniques simulations for ground-penetrating radar (GPR) (Warnick, 2020).	6

Difficult topics in Electromagnetism

The Electromagnetic Transmission class has been famous among students for being very difficult, not only about the subject being worked on, but additionally, they must have very good concepts from previous courses, such as physics and vector calculus, topics that have historically been difficult for them.

The students were asked using a survey about their perceptions about the difficulty of the course (at the beginning and the end). Table 2 shows that there is a preconception with low favourability about the difficulty of this class, which improved at the end of the class.

Table 2. Survey scores in 2015 and 2018 about the perception of class difficulty

Item	**2015**	**2018**
What was your perception of difficulty in the Electromagnetic Transmission course before starting it?	4.17/5.0	4.35/5.0

The perception of difficulty among the students who are going to start the class is quite high.

Additionally, based on the historical results of the evaluations, the three themes that generate the greatest difficulty in the students' learning process and some of their possible causes have been identified:

• Electrodynamics from the perspective of Maxwell's equations, which results in students thinking that Maxwell's equations are just equations, in which one must learn about mathematical vector operators, but no information is obtained about how the energy through an electromagnetic field, students consider electric and magnetic fields to be static.

• The dielectric properties of materials, since the students, still have a Newtonian vision of the physical world and in this way, the permeability, permittivity, and conductance do not fit into the model they brought.

• The perspective, utility, and applicability of electromagnetism in your professional life.

PROPOSAL USING THE CDIO FRAMEWORK

From the diagnosis made, we considered ways to improve and facilitate student learning in the subjects and the application perspective of electromagnetism. To meet these objectives, we developed a course methodology based on the CDIO framework, with active learning through PBL. Table 3 describes the four stages of the CDIO framework used to develop the projects proposed in this course; depending on each project, different stages were addressed.

Table 3. Stages of the CDIO framework used to develop the projects in this course

Stage	Description
Conception	The teacher shows the relationship between the project, the related concepts, and the expected learning outcome in the development of the project. By engaging students in thinking about concepts, new knowledge, and the need for open response, students enhance not only their learning process but also their deep understanding of what and how they learn (Crawley, et al, 2014)
Design	This stage is carried out in working groups and with the teacher's guidance, students must define the components and tools that are involved, develop the plans and algorithms for the project, and design the result of the project.
Implementation	In this stage, the students materialize the proposed design (hardware, software, testing), validate the accomplishment of the given restrictions, and evaluate the degree of compliance with the requirements indicated in the conception and design stages.
Operation	This stage involves demonstrations of the prototype (software or hardware). It allows students to understand their prototype working in the real world. Additionally, they can obtain feedback from users (other students) and an expert (teacher). As part of the final evaluation, they must present a written technical report in IEEE format.

With the CDIO framework, students develop their projects in such a way that, by acquiring knowledge and putting it into practice, they improve their team work skills, develop their critical thinking and strengthen their written and oral communication skills (Crawley et al, 2014), (Bravo et al, 2018).

PROJECTS DESIGNED FOR STUDENTS

Given that three topics generate the most learning difficulties, we created one project for each. Table 4 describes the three projects:

Table 4. Description of the projects

Project	Description
Vector Analysis of electromagnetic fields.	The motivation of this project is directly related to the abstraction of how a dynamic electromagnetic field propagates energy in a dielectric media as a wave. The students, as part of their active learning, (Standard 8), are asked to use Matlab as a visualization tool with an initial question on how an electromagnetic vector field can visually being represented with a proposed SteadyState Electric field expression. With the proposed expression students must obtain the magnetic field component by using Maxwell's equations. Having both field expressions, they are asked to include time dependence and propose a visualization method to show and explain intuitively the energy propagation phenomena. Then, students are asked to set up an additional propagating wave changing from a cartesian to the cylindrical or spherical coordinate system.
Dielectric-properties measurement system	The motivation of this project is to show the importance of knowing the dielectric properties of materials where electromagnetic waves propagate. Into the given context, students must acquire in-depth insights about the meaning itself of the permittivity, permeability, and conductivity of materials, besides how these concepts can be applied in radio waves propagation, materials characterization for diverse purposes. In this project the students must: 1. Designing, modeling, simulating, and implementing the selected method, including the excitation coupling. 2. Measuring the implemented method to validate the theoretical and simulated results. 3. Once validated, using the implemented method obtaining the dielectric properties of a liquid, solid or semi-solid load. Integrated learning experiences (Standard 7). 4. Comparing the obtained dielectric properties of the load with a valid dataset.
Impulse-based Ground Penetrating Radar (GPR) simulation for landmine detection	The main motivation of the project is to show students how the main concepts taught during the course can be applied in a real scenario. The problem exposed in the project has a direct impact on the national context since Colombia is one of the countries most affected by mines in the world with more than 11 000 registered victims since 1990. During the project development, students address important course concepts such as wave propagation in different media, reflection, and refraction of electromagnetic waves, wave velocity and time of arrival, electromagnetic computational time-domain methods, space domain discretization, and microwave imaging concepts. Students are asked to implement and simulate a 1D FDTD method by setting up the distance of the space domain, the grid points, the grid parameter, the excitation signal, and the boundary condition. In this fashion, they need to adapt the simulation set up with different landmine scenarios considering the air-soil discontinuity and the presence or absence of the explosive artifact.

DATA COLLECTION AND RESULTS

Data collection occurred over five years (since 2015). Two types of data were collected. The first was the final grade and GPA on a scale of 0.0 to 5.0 (the passing grade is 3.0). These data were collected in 2015 and 2018 for all 323 students. Measurements of central tendency and variability were found using descriptive statistics. After t-test was performed, there were no statistically significant differences between the GPA of students registered for the traditional class (3.83/5.0) and students registered for the PBL course (3.81/5.0).

The results of the students in later courses were also investigated, without obtaining any statistically significant difference. The results also indicate that student participation in the PBL class did not affect the percentage of students who failed the next electromagnetism course (Antennas). 21% of the students enrolled in the PBL course failed the Antenna course later, while 20% of the students enrolled in the traditional course failed the Antenna course later.

Nonetheless, there was a slight difference (although not statistically significant) of the percentage of students whose grades were above 4.0 in the Antennas course: 20 % of the students registered in the PBL class and 17 % for students registered in the traditional methodology class had a final grade above 4.0.

The second dataset was collected with a survey distributed in 2015 and 2018 (N=323, response rate=95 %). The survey has three parts. The first part asks students for their perceptions about the difficulty of the course at the beginning and the end of the course. The second part asks about the effectiveness and acceptance of the instructional strategy used. Finally, the third part of the survey inquiries about students' perception of learning in some specific concepts of the course. To reduce bias, these surveys were conducted before the students knew their final grades.

The four most relevant positive results in both surveys are mentioned in Table 5.

Table 5. Survey highest scores in 2015 and 2018

Item	2015	2018
What is the perception of the difficulty of the Electromagnetic Transmission course, when the course is ending?	3.57	3.36
Did you learn the concept of propagation of incident, reflected, and transmitted electromagnetic waves?	4.17	3.98
Did you learn the concept of dielectric characteristics of materials?	3.98	3.93
Did you learn the concept of Maxwell's equations and their use?	4.04	3.93

Additionally, other results have been obtained in terms of the perceived learning about the subjects of the course. These have remained at the same level except for Maxwell's Equations that lowered their rating. More than 80% of the students said that the teacher has been decisive in the perception of the course. Regarding the evaluation of the learning obtained by the students, more than 82% of them rated their learning process about electromagnetic wave propagation concepts over 4.0. A similar grade was obtained on Maxwell's equations and their use. In addition, more than 75% of the total students scored with 4.0 or higher in their learning process about the dielectric characteristics of the concepts of the materials.

Likewise, the three most notorious results that should be improved in our course are:

- After having completed three-quarters of the course, only 35% of the students thought they would pass the course.
- About 25% of the students scored with 2.0 or less the benefit-cost value of the class.
- About 30% of the students, gave a grade of 2.0 or less their learning and clarification of concepts about computational numerical methods in electromagnetism, including the utility of the project about the measurement of dielectric properties of materials through a resonant cavity.

In the same way that the highest scores were maintained between the two surveys, the three lowest scores are also maintained in both surveys and correspond to the learning of computational methods. As shown in Table 6.

Table 6. Survey lowest scores in 2015 and 2018

Item	**2015**	**2018**
How effective was it for learning the concept of numerical computational methods in electromagnetism?	3.04	3.09
How effective was it for the CLARIFICATION of the concept of numerical computational methods in electromagnetism?	3.02	3.00
Did you learn the concept of computational numerical methods in electromagnetism?	3.09	3.13

The positive effects perceived in students registered in the PBL class compared to the traditional class was also validated since its implementation in 2015, the number of capstone projects related to the area of electromagnetic transmission has increased more than 40%, as well as the number of students (more than 50%) in the elective classes related to these topics (optical transport networks and wireless communications). Also, after 2014, due to the greater interest generated in the students in the area of electromagnetism, students participated in external events and competitions of this area with very good results, among these achievements, the first place obtained in the design, implementation, and operation of an antenna for the reception of environmental images from the National Oceanic Atmospheric Administration (NOAA) satellites stands out.

DISCUSSION AND FUTURE WORK

The results show that there are no significant differences between the academic performance in the Electromagnetism course or the subsequent Antennas courses, between the students who took the course with the traditional methodology or those who took it in the course with PBL. What has been presented has been an increase in the number of degree work related to the subject of electromagnetism. This could indicate that there are no great differences between the learning of the students who were in the traditional methodology and those who applied PBL, however, it does show that there is much greater interest in continuing to work on the subject of electromagnetism in the students who had to carry out the different projects.

Despite the perceived difficulty of the subject, when students develop the projects proposed under the CDIO work methodology and show both the application and development of the concepts discussed in class, improvements in their attitude and learning are evident, thus the course has greater acceptance and thanks to the projects the learning has been more enjoyable according to their own opinions.

On the other hand, although the applied methodology has been essential to reduce the perception of difficulty. However, resonant cavity project needs to be evaluated in detail, either by changing its approach or the evaluation methods. Nonetheless, the course structure aligns very well with the CDIO approach implemented in the electronics engineering program.

Beyond maintaining the high results on the perceptions of difficulty, effectiveness, and acceptance of the instructional and learning strategy of the students, the data shows an increase in the participation in workshops and competitions of electromagnetism applied outside the university, even obtaining awards and recognition for projects related to electromagnetism. Therefore, continuous work should be promoted and maintained in the creation, design, and implementation of more projects related to the applied electromagnetic course and even previous courses, which help to demonstrate the application of electromagnetic theory, motivate students and reduce your perception of highly complex problems.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

The authors received no financial support for this work.

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