Methods Used to Increase and Promote the Academic Interest of the Electromagnetic Compatibility Course Content in the Engineers' Education

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Abstract **– Electromagnetic compatibility (EMC) is an academic subject which, due to its mathematical support, is considered to be difficult by the students. Multifarious methods have been applied in order to increase the academic interest of this subject. They include project based learning (PBL)–type activities for the laboratory sessions and within the framework of some elective activities. Students are interested in the current problems of society, so addressing some problems that concern the modern world, such as the effect of electromagnetic radiation on health, contributes to increasing the academic interest in the subject. The methods described in the present paper have led to an increase of the academic performance, which stands as proof for a smaller number of students who need to retake examinations, for higher scores and even the publication of scientific papers with the students' input.**

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1. Introduction

The electromagnetic compatibility academic subject is supported at *TRANSILVANIA* University of Brasov, Romania, within the framework of the Faculty of Electrical Engineering and Computer Science in several study programmes, such as: Applied Electronics, Electrical Engineering and Computers (in English), Telecommunication Systems and Technologies, Electrotechnics. The theoretical part of this academic subject is difficult and this is the reason why students must be stimulated to learn approaching modern issues and challenging topics while applying theory into practice. EMC is an academic subject which is taught at the study programme of Electrical Engineering and Computers in English. Thus, difficulties are doubled. On the one hand, there is the difficulty of a theoretical subject and, on the other hand, the difficulty of the English language. Teaching EMC in English is challenging and not easy at all. Students should be able to know not only theoretical things on EMC, specialized words and phrases, scientific methods, but they should also master the English grammar: moods, tenses, phrasal verbs and idioms, spelling and pronunciation in English.

A defining aspect for the current educational context is the great variety of the information sources, so that students should be trained to become more creative, to make connections between subjects, to build bridges across topics, to select the most appropriate and reliable sources of information as well as to be able to integrate the acquired knowledge in their own works and studies.

Thus, in [1] upgrading the academic curricula is suggested, preserving as many courses as possible from the existing ones, but combining them with the skills requested by the employers and using the project based learning (PBL) as a method of learning. [2] approaches the development of the students' creativity suggesting its training both during the lectures and through competitions, the positive outcomes being combined.

In the field of EMC there are certain peculiarities, one of them being the high price of the equipment used in the laboratory. A solution suggested in [3] is the use of previously utilized equipment, some items of equipment being already removed from service in order to offer the students a more practical activity. This method was also applied to the achievements presented in this paper, by using in the laboratory some pieces of equipment previously bought for research. The theoretical complexity is another feature of the EMC field of study. As a solution to facilitate the understanding of the phenomenon in [4], a suggestive data visualization method is proposed, data being acquired from EMC experiments, which make their understanding easier. A graphical user interface (GUI) is suggested in [5] as it makes the propagation of the electromagnetic field easier to understand. The principles of gamification applied in EMC [6] represent an interesting initiative under the form of a competition among students who had to measure the intensity of the electromagnetic field with cheap and ordinary laboratory equipment, the focus being laid upon their creativity. The authors of the present study suggest the use of simulations instead of analytical calculations to determine the electric field shielding attenuation.

The scientific community makes efforts to increase the academic interest of the electromagnetic compatibility course content. The EMC applications used in the current and highly promoted fields are highlighted for teaching purposes. Some of the most promoted phenomena are the theft of electronic information and the cyber attacks. The attackers can also use the power supply variations of the computing units or the generated electromagnetic field [7], [8], [9], all these being important elements that are the object of the EMC study. The students immediately become attentive in class when these phenomena are presented. The electric vehicles represent another topic that captures the students' attention. A few EMC aspects, taken over for instance from [10], are presented in front of the students taking into account the increasing popularity of the electric vehicles.

Recently, there have been many concerns among the population regarding the effect of electromagnetic radiation on health.

Regardless of whether the concern is justified or not, the approach from this point of view of the electromagnetic compatibility brings more interest for the academic subject. The first method of updating and increasing the academic interest of the suggested subject, which was also applied by the authors of the present study, was the electric field intensity measurement and the protection against exposure by shielding.

The company position on this issue is epitomized by the World Health Organisation, which has a clear stance on both the low-frequency radiation of the electricity distribution lines and the high-frequency radiation of mobile phones. "Based on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields", "To date, no adverse health effects have been established as being caused by mobile phone use" (www.who.int). However, the highly cited scientific research papers question the conclusions drawn by WHO. Paper [11] analyses the carcinogenic effect of the electromagnetic field in children, and paper [12] highlights the cellular changes. More cautiously representing its claims, the International Agency for Research on Cancer (IARC) considers the electromagnetic field to be possibly carcinogenic (Group 2B) (www.iarc.who.int). Most of the concerns are about high frequency communication (5G) [13].

The students manifested a high interest in this type of information, therefore it was considered that approaching some EMC issues from this point of view could increase the enticement of the academic subject and implicitly the learning outcome could be better.

2. Shielding Efficiency Study for Some Nanomaterials

At the beginning of the semester, a first course, in which the effect of electromagnetic radiation (that is, non-ionizing) on health is approached, starts with both the official position of the World Health Organization and the scientific articles which are the pros and cons of this position.

One of the methods of protection against the electromagnetic radiation is shielding. The emergence of the smart home concept has contributed to the development of new electromagnetic shielding methods and new materials with shielding characteristics, such as: 1. The large number of electronic devices with wireless transmission whose communication can be interfered and can be grouped according to their role in electromagnetically isolated enclosures; 2.

Shielding which reduces the exposure of tenants to electromagnetic fields.

For the assignments and works conducted during the laboratory classes dedicated to such aspects, simulation in SPICE and Matlab Simulink® was used in order to avoid the complex mathematical description of shielding, The transmission line was used as a model for the shielding material in which the parameters used were ε (electrical permittivity), μ (magnetic permeability), σ (electrical conductivity). The method was validated by the authors in [14] within the framework of a research contract through which the laboratory equipment was also purchased, then used in the laboratory. Estimating the attenuation of a material positioned at a distance from the electric field source is a simple process that can be easily applied by students who have experience working with simulations. The equivalence between the electric field shielding attenuation and the electric signals transmission attenuation through a transmission line was stated by Schelkunoff in 1943 and it is illustrated in Figure 1, where Ei and Hi are the input electric and magnetic field intensities and Eo and Ho are the output electric and magnetic field intensities, respectively, as well as Ui and Ii are the input voltage and current, and Uo and Io are the output voltage and current, respectively.

In the case of quantitative research, methodology should present the way numerical data was collected and how mathematical analyses are conducted to observe, analyse, access, and test experiments and hypotheses. Qualitative research involves collection and analysis of non-numerical data (e.g. text, video, or audio) with the aim of explaining concepts, opinions, perspectives, or personal experiences.

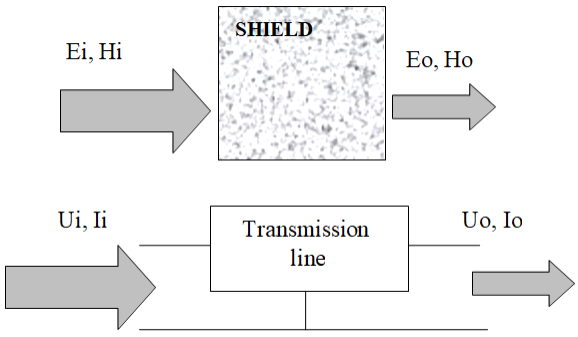


Figure 1. Equivalence of shielding attenuation to the transmission of signals through transmission lines

First, the students do simulations with the data provided for various materials, here being included some nanomaterials with conductive inserts, existing in the laboratory.

Second, experimental determinations are made.

For tests, samples of nanomaterials are introduced into the TEM enclosure, which is connected by coaxial cables to the signal generator and spectrum analyzer (Fig. 2).

Another set of experimental determinations was made with a Gunn diode microwave waveguide measurement system. The system is closed from an electromagnetic point of view eliminating the influence of disturbing electromagnetic fields on the measurement process. The material samples subject to the measurement process are arranged in the rectangular waveguide in which the microwave field (10GHz) is generated. The measurement system consists of the following elements: microwave generator with Gunn diode, rectangular waveguide consisting of sections connected by flanges, variable attenuator in the waveguide, field detector with high frequency diode, power detector (Figure 3). At the end of the laboratory works, students compare the results obtained by simulation with those experimentally obtained by the two methods. Comparative data between a copper foil shielding and conductive insert naomaterials are shown to the students and the differences between the simulated and measured values are explained to them by the instructor. The simple and intuitive approach to shielding as well as getting the students conversant with the EMC-specific test equipment made these papers to be highly valued. A simple test with the introduction of a smartphone into the TEM enclosure proves that the phone is no longer accessible either by GSM, Bluetooth or wireless, and the experiment has always been a great success among students.

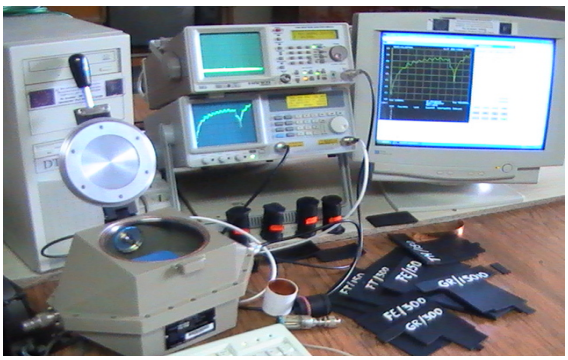


Figure 2. TEM measurement system

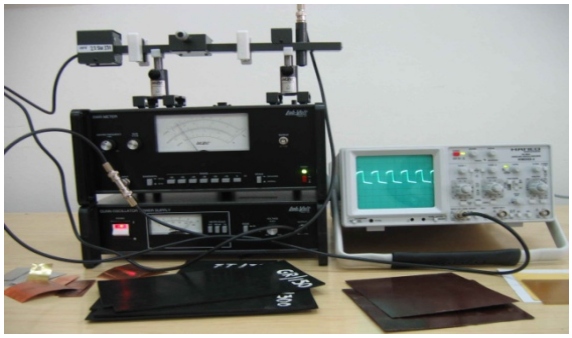


Figure 3. LABVOLT waveguide material attenuation measurement system

3. Checking Life Protection Devices from the EMC Perspective

The laboratory works on this topic tackled the issue of electronic devices dedicated to the protection of life, particularly electronic fuses. As an electronic fuse used in the laboratory, a prototype was created within the framework of a research project (which ensures disconnection of the load in case of overcurrent, overvoltage, short circuit and electric arc) [15]. The determinations were made with specialized equipment in the EMC laboratory of the faculty and in the anechoic chamber of the University Research Institute. There was used the electromagnetic radiation measurement equipment as well as means of automatically testing the generated conducted disturbances and the immunity to conducted disturbances, respectively. The academic interest of these laboratory works was due both to the familiarity with the prototype of the electronic fuse under testing and to the modern EMC testing equipment used in the laboratory. Images of the working environment are given in Figure 4 - an image taken from the anechoic chamber where the electromagnetic radiation emitted by the fuse is measured.

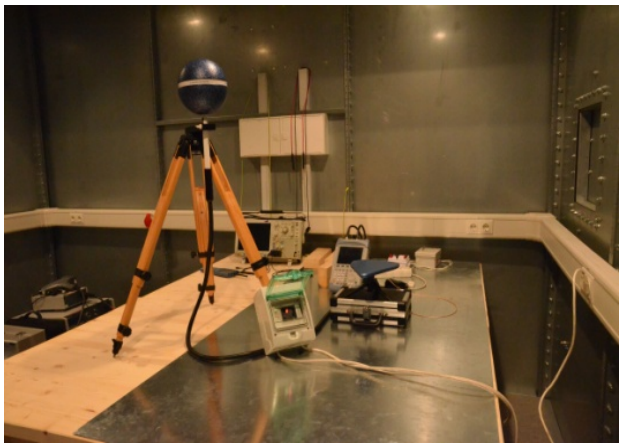


Figure 4. LABVOLT waveguide material attenuation measurement system

In Figure 5, there is the Netwave 30 EM Testing Stand equipped with data acquisition and specialized software for electromagnetic compatibility testing. The tests were conducted by connecting purely resistive, resistive-inductive, resistive-capacitive and RLC loads. Another type of tests was the electrostatic discharge test-type (Fig.6).

The European testing standards as well as the compliance verification within the required limits and regulations were presented during the laboratory sessions.

The standards according to which the tests were conducted were EN 61000-3-2 - limits for harmonic current emissions, EN 61000-4-11 - immunity tests for voltage drops, short interruptions and voltage variations, 61000-4-13 - low frequency immunity tests, 61000-4-14 – voltage fluctuation immunity test, EN 61000-4-28 – immunity test to voltage supply frequency variation, EN 61000-6-3 - standard of emission for residential, commercial and slightly industrialized environments.

Figure 5. Conducted disturbance measurement

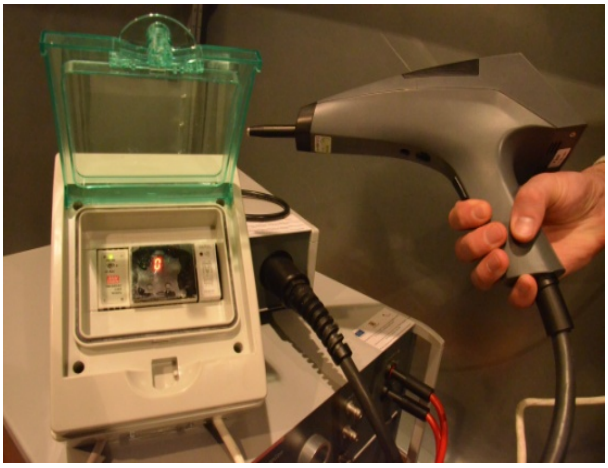


Figure 6. Electrostatic discharge testing

The tests presented to the students were designed within the framework of a research contract and afterwards they were also published [16]. The tests resulted in reports generated by the test equipment.

They were analysed and discussed with the students. Figure 7 shows an example of such a report for the fuse injected harmonics in the network in the case of RLC loads with different numerical values. The graphical representation is high for the harmonics frequency up to 2500 Hz, and the maximum allowed values are shown at the top of the graphical representation. The students' attention is drawn to the framing of the harmonics amplitude within the maximum allowed values.

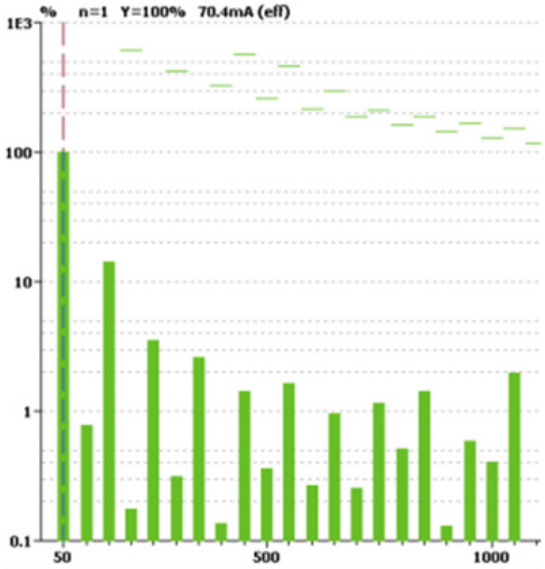


Figure 7. Example of Report Generated by Netwave 30 EM Test (50-1000 Hz Range)

The conclusion drawn after carrying out these laboratory works is that EMC tests are important in the case of the electronic devices on which people's lives and safety depend. The safety of their operation also depends on their immunity to disturbances, and the tests conducted with the Netwave 30 EM Test Stand show that the tested electronic fuse meets the immunity requirements.

4. Measuring the Electric Field in Various Locations and Compliance Verification within the Maximum Allowed Limits on Elective Trips

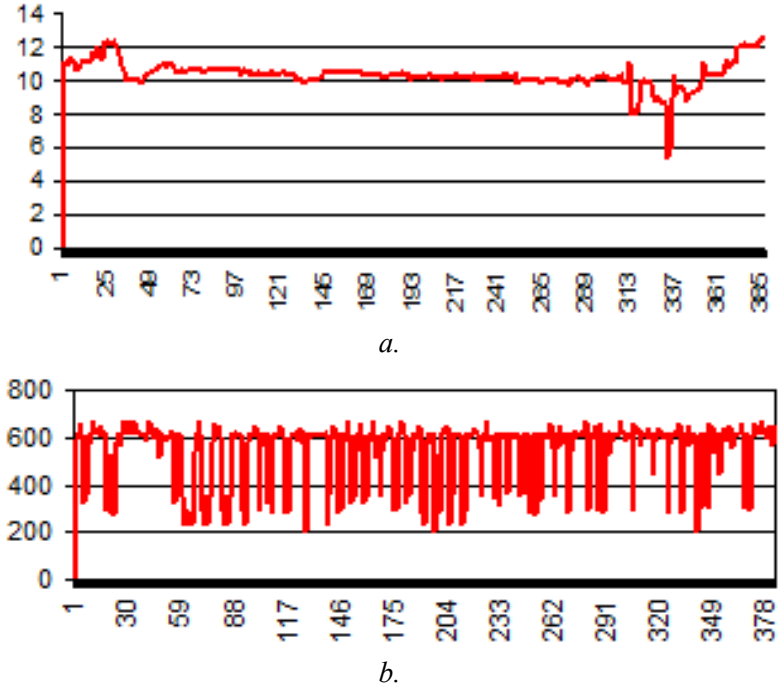
The electric field intensity measurement is an aspect of interest for students, and the initiative to interweave this interest with trips organized in the middle of nature has been very successful. The electric field measurements were made in two frequency ranges where the field intensity can be higher, that is, in the low frequency range around 50Hz frequency and in the high frequency range of mobile communications.

The electric field measurements were performed with two SPECTRAN spectrum analysers, one in the 1Hz-1MHz range (NF 5010) and the other one in the 1MHz-6GHz range (HF 6060). The analysers are portable, store a certain number of measurements and can transmit the measured data via a USB connection to the computer. The assisted computer data processing allows further processing in Excel bringing a great contribution to the understanding of electrical phenomena.

The intensity of the electric field generated by the electricity distribution was measured in the case of the determinations made at low frequency (50Hz). A wooded area, over which the distribution lines pass, was chosen as the location of the measurements. Images during the measurement trips are given in Figure 8.

Figure 8. Images from the trips on electric field measurement

It can be seen that at 200m of lines, the intensity of the electric field is about 10V/m, and at 20m of lines, it is 600V/m, the graphical representation being given in Figure 9. The maximum values of the electric field are obtained at the nominal frequency of the network (+/-3Hz) and are below the maximum allowed ones by the European legislation.



a.

b.

Figure 9. Maximum electric field values in V/m at 200m of lines (a) and at 20m of lines (b) (Samples of the Field Value at the Nominal Frequency of the Network are on the Abscissa)

Measuremets were also made in the 1MHz-6GHz range to determine the electric field strength in the frequency ranges used in mobile communication. The measurements were made near a mobile communication relay located on a mountain close to the city. There have been identified the frequency bands allotted to different communication modes (3G, 4G, 5G) and different mobile service providers. In all the investigated cases, the electric field value was below the maximum allowed one by the European legislation.

5. Results Obtained in the Teaching Activity

First of all, the knowledge acquired in the EMC academic subject contributed to the BSc Projects. The Bachelor of Science Projects frequently integrate EMC notions. For example, the projects containing hardware implementations use methods reducing the conducted and radiated disturbances by designing wiring routes and using shielding. Upgrading the activity of the EMC academic subject brought benefits, thus, coming into being BSc projects closely connected to this field. For instance, a student designed a wireless controlled mobile wheeled assembly, which measures the intensity of the electric field in transformer stations, where the maximum values allowed for human operators are exceeded. The mobile assembly is presented in Figure 10.

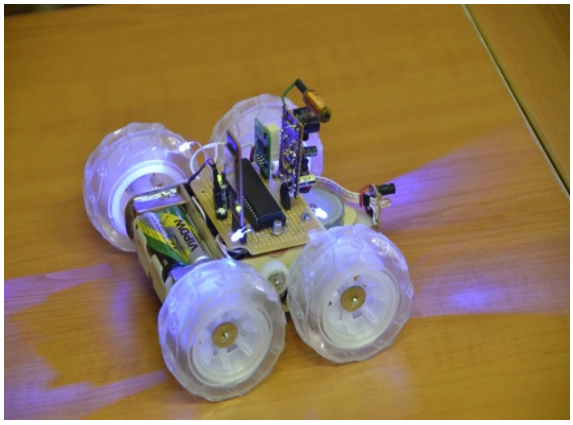


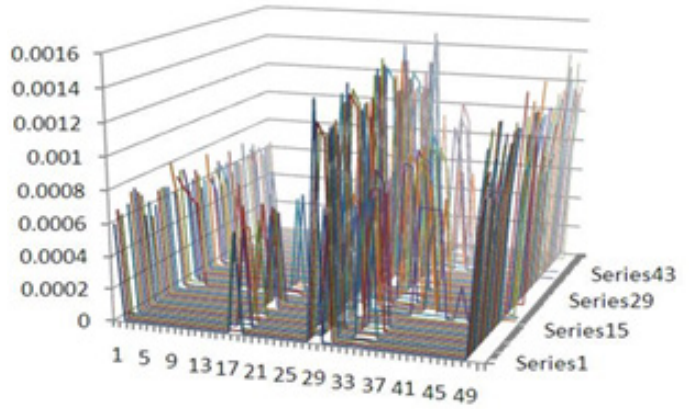
Figure 10. Wireless controlled mobile assembly for electric field intensity measurement

Another highly praised BSc Project was an EMC study on wireless transmission methods between the engine compartment and the cabin of a motor vehicle. Digital transmissions with FM modulation at various frequencies and Bluetooth transmission were tested with the engine off and on. A running spark ignition engine generates significant disturbances for the transmission module located under the hood.

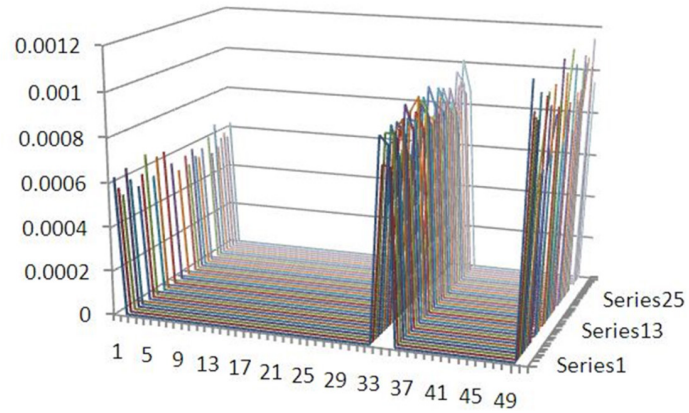
The speech defended on this paper at the Students' Scientific Communication Session generated multifarious debates, especially in the figures showing the spectrum measured in the engine room, Figure 11, with the engine on (Fig. 11a) and off (Fig.11b). The spectrum images demonstrated the importance of the communication analysis from the EMC perspective.

The intensity of the electric field was represented in V/m in the 400-450MHz frequency range, the transmission being carried out by FM modulation in the 433MHz free band.

The disturbances generated by the engine operation were seen very clearly and suggestively overlapping the useful signals.



a.



b.

Figure 11. Spectrum of an FM transmission in the engine compartment with the engine on (a) and engine off (b)

Figure 12 shows the evolution of the students' grades in between 2015 and 2023.

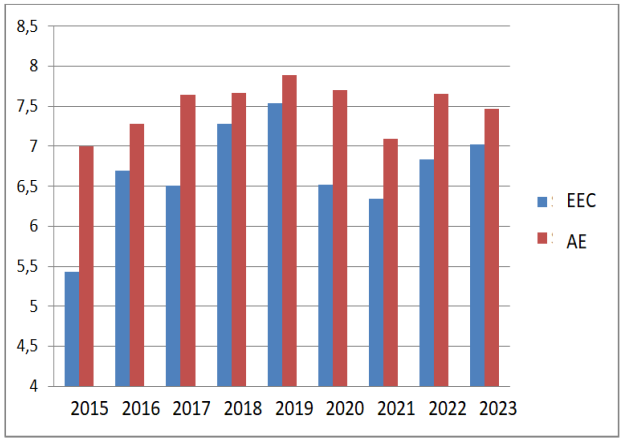


Figure 12. Academic performance

It can be noticed an increase of the academic performance after the gradual introduction of activities enhancing and promoting the academic interest of the EMC course content in the academic years of study.

The transition to online teaching obviously led to a decrease in the academic performance in the 2019/2020 and 2020/2021 academic years, and after coming back to the hybrid and face-to-face learning, academic performance acquired higher values. It was graphically represented the evolution of the students' average scores at the study programmes of Electrical Engineering and Computers (EEC) and Applied Electronic (AE). In order to identify the students' opinion on the EMC course, a pilot study was carried out, dedicated to the 4th-year students from the electrical engineering specialization and the 3rd-year students from the applied electronics specialization.

The main objective was to determine the students' professional satisfaction towards this course, and the secondary aim was to establish some correlations between the attitude towards the EMC academic subject and the academic performance in this subject. The academic performance was measured by the scores obtained.

This subject is considered to be a medium one in point of difficulty. Regarding the importance of the subject, 58.8% consider it to be important and very important. 70.5% of the students consider that they were interested and very interested in the academic subject, and 64.7% consider that they were motivated to learn, the stimulation being appreciated by them as good and very good. A high percentage of 70.5% of students declare themselves satisfied and very satisfied with this academic subject, and the academic performance is closely related to the degree of satisfaction. Students appreciated the support provided by the simulation software (Spice and Simulink). Their use shortens the time it takes to solve an EMC problem. For instance, one group of students had to solve a shielding problem by analytical calculation and another group had to solve the same problem by simulation at an examination. The average solving time by means of the analytical method was 73 minute and by simulation, it was 41 minutes, respectively.

6. Conclusion

The additional activities within the framework of the laboratory works and the trips to measure the electronic field as well as the debates focused on the previously specified directions achieved their goal, namely, that of increasing and promoting the academic interest of the EMC subject. Immediately after the first year of applying the trips for field measurement (2012), the positive perception on the academic subject has improved. The large number of students who took part in these elective activities and also the fact that students from other study programmes (e.g. Computers) started to participate stand as a valuable proof for all the registered improvements. The EMC academic subject was previously perceived as a more theoretical course, and the difficulties in understanding the electromagnetic field theory made it less attractive. The connection between EMC and radiation health concerns, the laboratory work with modern test equipment and field measurement trips had the effect of increasing the students' interest and the academic performance. As a secondary consequence, the relationships among students were strengthened by group trips, often accompanied by friends, some of them being students at other faculties. Even the students from other faculties were interested in debating the pros and the cons of the electromagnetic radiation danger. The participation of some students in the Scientific Communication Session with papers in the EMC field also proved the improvement of the perception on this academic subject.

Thus, a simulink simulation work of GSM transmission was particularly successful being taken into account both the attenuation of the signal between the transmitter and the receiver due to distance, but also due to the movement of the receiver relative to the transmitter (simulated by Rayleigh fading) [17]. Passionate students were willing to work with the teaching staff on research projects and became co-authors on published works, for example [16]. The current trend lays emphasis upon the students orienting themselves towards academic subjects which offer them the knowledge required by employers at present (e.g. programming) and their attitude of neglecting theoretical subjects, such as EMC. The measures used to increase and promote the academic interest of the EMC course content in the engineers' education were of paramount importance in this context in order to gain the students' interest and to provide them with a broad-spectrum training covering all the possible changes which might occur in the direction of technology in the future.

Educators should teach students ways to overcome the previously mentioned difficulties training them to be able to cultivate relationships, to include game-design elements in their study by using gamification, to motivate them by approaching modern and challenging topics stimulating their creativity, to develop their language skills across all curriculum topics building bridges across topics, to find and use reliable sources of information, to integrate the acquired knowledge in their own works, studies and papers as well as to monitor their achievements.

The students' academic interest should be increased in theoretical subjects taught in a foreign language by making reasonable demands and encouraging them to take part in the suggested activities by offering them small incentives in order to give them a sense of accomplishment.

The results obtained through the methods presented in the paper were appreciated by the faculty management and it was recommended to adopt these methods in other academic subjects as well. Also, the knowledge of Matlab Simulink® was useful in carrying out simulations in several academic subjects, and some students carried out EMC tests of their Bachelor of Science projects.

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