Teaching Electricity and Magnetism in electrical engineering curriculum: applied methods and trends

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Abstract .
In this paper, the authors will attempt to describe their experience of teaching the fundamental concepts in Electromagnetics (EM) at the undergraduate level and will describe methods which they consider have pedagogical advantages and are better suited to the new European higher education environment conve ned in Bologna in 1999 (The Bologna Declaration (BD), a pledge by 29 countries to reform the structures of their higher education systems). Some of the authors have more than 15 years experience in higher education, and all of them have had duties dealing with teaching EM theory. The authors have experience in university activities, not only in lecturing but in organisation, direction and planning teaching activities and, in recent years, they have also taken part in the development of strategic plans and a ccreditation of new engineering curriculum aiming to create convergence in European higher education under BD.

The change process has been performed smoothly since 1995. New teaching resources have been introduced. The mathematical skills demanded by the subject has been adapted to the level of the incoming students. Some real - world applications (already adapted to the students' level) have been proposed to increase motivation. This paper shows results of students' surveys that are analyzed and from conclu sions are made.

Index Terms *— Electricity and Magnetism lecturing, electrical engineering, Bologna Declaration, Spanish university, teaching resources, seminars, undergraduate education.*

INTRODUCTION

The University of Zaragoza is one of the 50[1] Spanish public universities. It has an annual budget of € 188 700 000, with 70% of the funds coming from the national or regional budget. It offers 31 short cycle degree programs and 24 long cycle degree programs. Short and long cycle degree programs are organized by centers or faculties. The departments manage and organize the doctoral programs and the research activities; they are also in charge of teaching and laboratories responsibilities.

The 2796 professors and lecturers have bachelor, master and doctoral degrees, and 62% of them are civil servants. The 32% of the university personnel are management and administration staff (1344 employees, with a rate of 84,5% of civil servants).

[1] The following data refer to 2003, unless otherwise specified.

Zaragoza University has 37 258 undergraduate registered students, 48,9% in short cycle degrees –usually 3 academic years– and 51,1% in long cycle degrees –usually 5 academic years. The typical yearly cost of tuition and administration fees is around € 787. Moreover, 11% of the students received a tuition grant (2001 data). The 75% of the students come from other towns of the same region (2001 data). Dormitories are scarce and students usually live with relatives or they share rented flats, which are not subsidized. Students are represented in the governing board through the student unions of each center. In the last years, the interest of the students in the governing board seems to have decreased.

The Industrial Engineering Technical College of Zaragoza (EUITIZ) is one of the 23 faculties of the Campus. 169 lecturers and 31 management and administration employees are members of EUITIZ' staff. It has registered 3700 students. It offers Electrical, Mechanical, Chemical, Electronics and Industrial Design Engineering degrees. The relationship of EUITIZ with industry is low but there is a tendency to increase. Nevertheless, there are strong links with the Professional Association of Industrial Technical Engineers.

Nowadays, higher education of the European Union (EU) is experiencing big changes due to BD, modifying the majority of the basic structures of the courses. In Spain, this process requires both the revision of the teaching-learning methods and to restructure the university organization [1]. For a successful change, a broad social agreement between university and post-graduate engineers is demanded.

The subject Electricity and Magnetism analyzed in this paper is taught during the first academic year of Engineering. It is a two-semester subject of 120 lecture hours (90 for theory and conceptual applications and 30 hours for problem solving) and 15 hours of supervised laboratory work. The American equivalent would be a class lasting two semesters (a semester is equivalent to 15 weeks workload), with three semester credits for theoretical lectures, one semester credit for problem solving lectures and 0,5 semester credit for laboratory. The 334 registered students are divided into three lecture groups and 15 laboratory groups. This paper is focused on the teaching experience of the last 8 years and it describes the efforts made to update and enhance the subject.

Electricity and Magnetism is complex, difficult to learn and teach in Engineering curriculum [2] [3]. This might be due to some factors as:

- Some concepts are not intuitive and they are quite abstract.
- Electromagnetism phenomena cannot be experienced by human senses.
- Electromagnetism theory requires complex mathematical skills.

Thus, this subject does not appeal to engineering students and we have frequently noticed that engineers of our professional surrounding do not have good memories of it. Accordingly, this subject is usually one of the first subjects to be cut back on credits when there is a need for time in a new syllabus [4]. However, there is a general agreement on the importance of the skills acquired in this subject for electric and electronic engineers. These circumstances characterize the main features of the electromagnetism teaching methods:

- Increase in motivation
- Graphical visualization of mathematic concepts
- Closer contact with real-word applications
- Direct experience and laboratory work.

Sudden changes in education might cause confusion among lecturers due to insufficient skill and experience in the new methods. This could lead to the rough implantation of formal parts, disregarding the underlying issues involved in those changes. Therefore, we have followed a continuous evolution from the former system to the new one through small changes. Along the following paragraphs, we will present our work, consisting on the progressive enhancement of the teaching techniques applied to Electricity and Magnetism. This change has been possible due to freedom of lecturing highly respected in Spanish universities, despite our rigid syllabus system.

WHY AND HOW DID WE CHANGE?

The initial motivation for changing was the generalised complaint from the students about the underlying mathematical burden and the scarce real-world applications shown at class. The fact that a big portion of our students comes from vocational training instead of high school highlighted the inadequacy of the level and the effort demanded. The academic failure was high but comparable with others of similar subjects of the first year of engineering, so it was not a main reason for change at first.

Our teaching-learning process is still based mainly on lectures. In spite of some teaching tendencies that criticise lectures [5], others still consider them as an efficient, structured and appealing way of transmitting knowledge [6]. The adequate performance of a lecture should require:

- Wide teaching experience and to keep the subject in perspective.
- Good classroom discipline for an adequate learning atmosphere.
- Academic institutional support by means of human resources and funds.

When the former conditions are met and complementary activities for enhancing learning are performed, lecturing can reach a high quality level and it can be a cost-effective teaching method. Nevertheless, the never-ending changes that education is experiencing nowadays requires other teaching systems to be considered and tested, like new technologies among others.

The influence of computer-based teaching and multimedia is increasingly strong. Its implementation can be performed in several ways:

- Databases to share teaching resources for students and teachers [7].
- Internet-based system for optimizing learning and enhancing understanding, ranging from systems that collect and systematize information, self-learning and self-evaluation [8] [9] up to ebooks [10] [11].
- Presentations and animations to be shown in class and for individual study [6] [12].
- Simulation programs to approach complex real-world applications for students [2] [13] or as a support for a general physics subject [14].
- Other teaching applications of new technologies such as computer games [15]

Despite the undeniable advantages of the new technologies applied to learning, there are some drawbacks that should be highlighted: the lack of contact with real devices; the apparent simplification of very complex models; high consumption of time demanded by some available resources. Therefore, new technologies are very suitable to enhance many learning features, but they are insufficient to replace the bases of the teaching-learning process of Electricity and Magnetism.

Moreover, educational research in physics teaching has lead to the application of modern cognitive theories in which the student plays a more active role than in conventional lectures. These methods are summarized in the active-engagement instructional methods [5] and they have reached a notable importance for teaching Electricity and Magnetism.

OUR EXPERIENCE TEACHING ELECTRICITY AND MAGNETISM

The contents and the original approach to the subject were quite theoretical and mathematical, corresponding essentially to the conception of classic electromagnetics texts such as Reizt-Mildford [16], Cheng [17] or Zahn [18]. Keeping the fundamental contents, the first transformation was to move from the differential description of the electromagnetic phenomena to a more intuitive approach inspired in general physics texts such as Resnick-Halliday [19], Serway [20] or Tipler [21].

The following change was the progressive introduction of problems related to real-world engineering applications (electricity in transportation, power transmission, lightning protection, sensors). Adaptation of real-world problems to a suitable level for freshmen is not easy: when we cross-examine important practical applications, modelling and mathematical complexities usually arise. Nevertheless, we have devised through the years a collection of problems related to real-world applications.

The next change was to include lecture demonstrations. The advantages of experiments supporting theory during lectures are widely recognised [22]. Should we mention the initiative of the compilation and systematization of physics demonstration through the US organization *Physics Instructional Resources Association* (PIRA) [23]. In the academic year 2003-04, 17 lecture demonstrations have been shown in class. The number of demonstrations is even growing since we still lack appropriate experiments for supporting some theoretical concepts. A summary of our experience in this field can be found in [24].

A closely-related aspect to lecture demonstrations is the optional laboratory assignment. This tool was established in the academic year 1996-1997 to help students coming from vocational training, with high handy and practical abilities but low mathematical skills. The assignments are mostly focused on the construction of prototypes, useful for class demonstrations and for supporting the theory. Prototypes improved during several academic years resulted in a collection of high added value demonstrations together with an increased motivation in the students involved in the projects. In the academic year 2003-2004, four students projects have been used for lecture demonstrations. A sample of some students projects can be seen in [25] [26].

Other activity of increasing importance for the systematization of teaching is the compilation and the classification of images, photographs, animations and other multimedia resources. We have gathered a satisfactory amount of teaching resources along our teaching activities. In the 2003-2004 academic year, these resources have been structured with Internet links and embedded images, animations and videos. Some of these resources are used at lectures; for instance excerpts from video collections [27] [28], visualizations from MIT 8.02 Electricity and Magnetism [29] and interactive programs [30] [11]. Now, these resources are available for the students through the web page devoted to the class (a sample of this media can be seen in [31]).

In the Spanish university, professors and lecturers have a duty of 6 hours of tutorials per week. These tutorials are not compulsory for students and they are often discarded for teaching activities. Another of our innovations has been their transformation into optional seminars where students can solve problems with the assistance of a lecturer. In a seminar, a lecturer is available for any questions that arise in the problem-solving process and to detect common errors. We consider this activity very useful to balance the initial skill differences among students and to increase the efficiency of the learning process. Moreover, theses seminars are a test bed for educational innovations with small groups.

In the academic year 2000-2001 the supervised laboratory hours was restructured, spliting those related to circuit theory from those related to fundamentals of electromagnetism. Nowadays, the students have an assignment of 14 supervised lab hours dedicated to essentials of electromagnetism in two-hour periods. They are currently committed to electrostatics (2 sessions), magnetism (3 sessions), simulation (one session) and demonstrations and multimedia (one session).

At last, we have emphasized the organizational part of the teaching-learning process. This includes a series of documents where the contents, objectives, assignments, reading list, useful Internet links and study recommendations are detailed and systematized. In this academic year (2003-2004), we have added the estimation of the workload for students and lecturers. This estimation is based on surveys carried out the former academic year and on the analysis of the students' duties. It is also needed for the European Credit Transfer System (ECTS) implementation.

The summary of the student workload is shown in the two columns on the left of table I. The 120 hours for attending lectures are divided in 90 theoretical lectures and 30 problem-solving lectures (each lecture has a period of 50 minutes). Some questions and answers are introduced during the lectures to increase the interaction with students. The self-study workload is computed as the necessary hours for revising the lectures with the reading list and for solving the proposed problems of each unit (in all, 85 workload hours are estimated for solving 90 proposed problems and 45 workload hours are estimated for studying theory). With the previous workload, a student should succeed in the first examination. However, we have added 20 extra hours for the preparation of a re-sit exam.

Table I: Student and lecturer workload

Student workload	**Hours**	**Lecturer workload**	**Hours**
Attending lectures	120	Lectures (3 groups)	360
Laboratory	15	Laboratory (15 groups)	225
Self study (including seminars)	130	Prep-time	510
		Tutorials	360
Re-sit exam	20	Exams	360
		Other academic training activities	150
Total	285	Total	1965

The summary of the lecturer workload is shown in the two columns on the right of table I. Lecture and laboratory hours correspond to supervised classes, so their account is straightforward. The prep-time account is based on lecturers experience with several years teaching this subject. The tutorial workload is based on real time spent with students, not the official hours set for each teacher. The exam workload comprises the creation of exam documents and the written solutions, surveillance, correction and revision; all this process is repeated for each examination. Other academic training activities comprise the time consumed in preparing experimental demonstrations, meetings about teaching activities, fulfilment of reports related to the subject, etc.

The surveys and the interviews with our students show that we may have overestimated the students workload (Table II).

Table II: Estimation of the students' workload (Academic Year 2003 – 2004)

Workload estimated by the lecturer (%)				
Excessive	Plenty of time	Enough	Short of time	Very scarce
4,7%	15,3%	49,4%	29,4%	1,1%
Real workload deployed by the student (%)				
Much more	More	Equivalent	Inferior	Very Inferior
15,1%	27,9%	26,7%	23,2%	7,0%

The flowchart in fig. 1 outlines the teaching-learning process. Theory and problems are lectured, being backed up by demonstrations and real world problems, and complemented with laboratory and other activities such as seminars and tutorials.

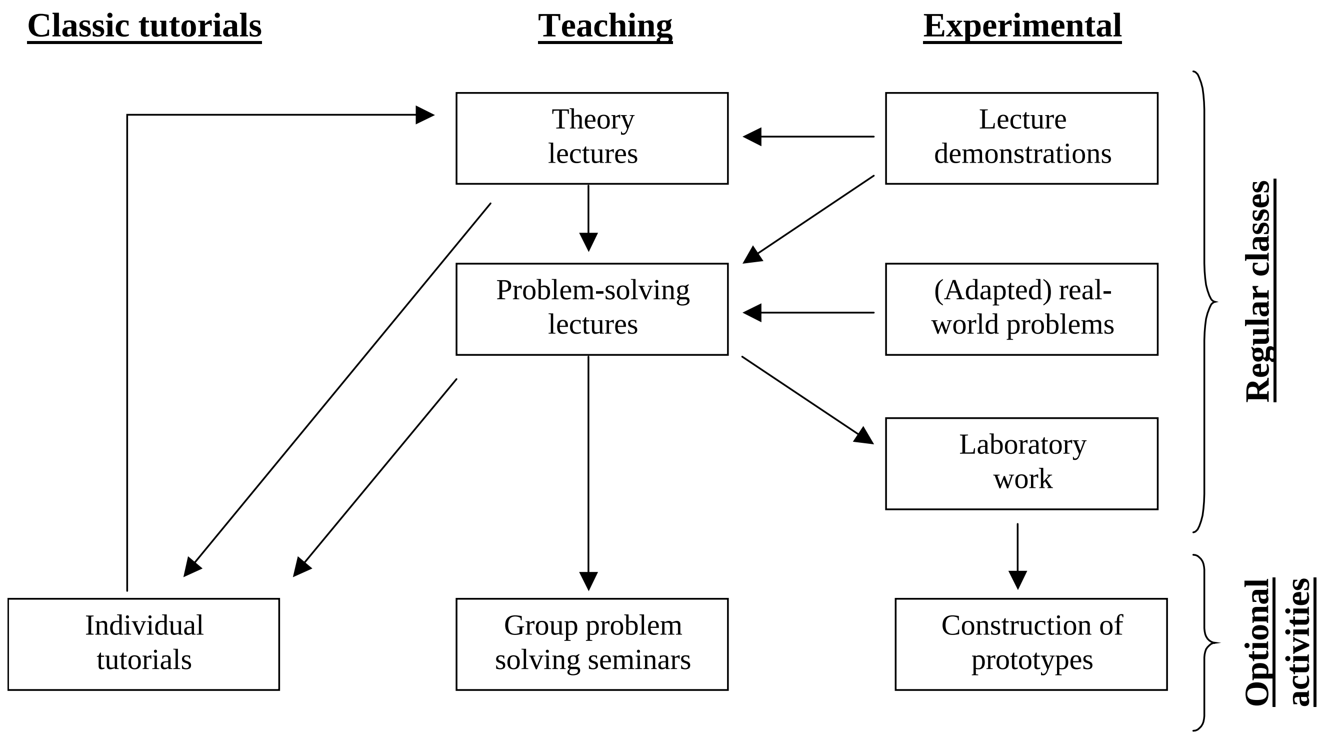

Figure 1: Flowchart of the activities involved in Electricity and Magnetism.

Finally, there is a summary of the activities introduced from 1996 up to now.

Table III: Main Activities Introduced

Real-world problems adapted to the class level.
Lecture demonstrations as a basic resource in lectures.
Construction by students of prototypes for lecture demonstrations
Use of multimedia presentations and other interactive resources such as web pages in class
Problem-solving seminars to increase skills and detect common errors
Organizational improvements (systematization of objectives, reading list, study recommendations and estimation of the workload)

Some teaching innovations have been explicitly supported by the University. Academic institutions have funded them since the academic year 2000-2001 through the official program of educational innovations. € 6000 have been received for the last four years; these funds have been essential for accomplishing the activities that required extra cash apart from the regular funding of the subject.

Results: Achieved goals and failures of the method.

An important tool to assess the changes has been the annual students surveys. We have analysed two different surveys each academic year. One is the official University survey, which tries to monitor the quality of the academic environment of each class. This poll was established a few years ago aiming to get anonymous information from the students about lecture activities, tutorials duties, laboratories, examinations, etc. These surveys are filled out during the last two weeks of the second semester. They do not give detailed information that we consider important in order to know how to change or what to improve in our course, so we decided to do another one focused just in our activities.

The most significant results of these surveys are listed in the following tables. In table IV the number of registered students is compared with the number of examinations being sat by the students each academic year. In table V the number of registered students is compared with the number of students attending class the last two weeks of the second semester. This figure is obtained from the number of official surveys filled out by the students. Table VI shows the results of our own surveys; for both questions, students where told to choose one of these five options: all, almost all, enough, little, nothing. Results shown in tables VII y VIII come also from our own surveys, and reveal the attitude of the students towards the method based in conventional lectures. Tables IX, X and XI show data from the official surveys. They are from a single group that has maintained the same lecturer over the whole period of study. For the three tables, the questions had five possible choices.

From the analyses of the results depicted in the tables and interviews with students, we can conclude as achieved goals the following:

- Students find the concepts of Electromagnetism a little easier (table IX), although they still consider them rather difficult to learn.
- Students consider Electromagnetism very important for their training (table X)
- Students think that the teaching resources have been improved and they are satisfied with the actual level of teaching resources (table XI)
- Laboratory sessions dedicated only to electromagnetic phenomena have also be very well received. Nevertheless, students find the contents of each session too difficult to deal with.

About the failures of the method, we may list the following:

- The engagement of the students is still very low (table IV) as well as the academic results (table XII)
- Attendance at second semester lectures is still quite low and has not been increased at all (table V)
- Students' benefits from conventional lectures have been improved. Nevertheless, higher level could be attained (table VI)
- The number of students engaged in voluntary work is extremely low, as it does not reach up to 5% of the registered students

Table IV. Academic engagement

	1998 - 1999	1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003	Total
Registered students	335	345	307	293	303	1583
Examinations being sat	211	259	222	154	176	1022
Examinations being sat (%)	63,0%	75,1%	72,3%	52,6%	58,1%	64,6%

Table V. Lecture attendance

	1998 - 1999	1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003	Total
Registered students	335	345	307	293	303	1583
Students attending lectures in the last two weeks of 2^{nd} semester	153	138	134	80	93	598
Students attending lectures in the last two weeks (%)	45,7%	40,0%	43,6%	27,3%	30,7%	37,8%

Table VI. Student benefits from conventional lectures

	1998 - 1999	1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003
Students understanding all or almost all the concepts presented	56,6%	60,6%	68,4%	45,0%	61,4%
Students understanding all or almost all the electromagnetic concepts presented after reviewing the lecture	60,1%	61,8%	70,7%	55,0%	68,7%

Table VII. Participation during lectures

	1998 - 1999	1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003
Students willing to participate	26,7%	27,1%	35,6%	42,3%	20,4%
Students not willing to participate	73,3%	72,9%	64,4%	57,7%	79,6%

Table VIII. Students' preferred lectures

	1997 - 1998	1998 - 1999
Interactive lectures	86,5%	77,2%
Conventional lectures	13,5%	22,8%

Table IX. Perception of difficulty of Electricity and Magnetism

	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
Very difficult or somewhat difficult	97,0%	94,1%	97,6%	92,0%	74,3%	87,8%	89,1%	83,9%

Table X. Perception of importance of Electricity and Magnetism for engineering training

	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
Very important or somewhat important	63,6%	75,0%	78,0%	73,5%	68,5%	79,5%	82,6%	91,7%

Table XI. Teaching resources used by the lecturer

	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003
Excellent or very good	67,6%	72,0%	71,4%	70,0%	86,1%	80,5%	82,2%	86,1%

The criteria for the evaluation of the students, which can affect the overall result of the method, can be also improved. Continuous evaluation, which is becoming strongly demanded by the students, is not yet implemented due to the high number of students. Our evaluation method consists of:

- A three-hour examination that contains three problems to be solved by the student using only a scientific calculator. The mark obtained in this exercise represents 90% of the final mark (minimum mark to pass: 5 over 10).
- Laboratory notebooks are revised by the academic staff in charge and evaluated; the mark represents 10% of the final mark (minimum mark: 5 over 10).
- The voluntary work can add up to one point over the 10 points basis final mark described above.

Table XII. Academic results

	1998 - 1999	1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003	Total
Registered students	335	345	307	293	303	1583
Students passing the class	119	122	130	91	111	573
Students passing the class (%)	35,5%	35,4%	42,3%	31,1%	36,7%	36,2%

CONCLUSIONS

The aim of this paper has not been a thorough revision of the teaching methods of Electromagnetism in Engineering, but we have tried to show our evolution and current results in order to contrast with other similar experiences. Indeed, the process of continuous change would make possible a smooth adaptation to the Bologna Declaration.

Our experience can be summarized in the following key points:

- The actual standard required is appropriate for freshmen and it is in agreement with the most usual reading lists for introductory Electricity and Magnetism classes.
- Although the teaching-learning procedure can be clearly improved, it is coherent with other models used nowadays. A compulsory enhancement should be to get the students a more active role.
- The low requirements to enrol and to continue in a course, together with the low cost of tuition and fees (that only reflects a small part of the real cost) and the present good socio-economic situation of our country can explain the relaxed approach of the students to the subject.

Therefore, we understand that the low academic results are not due to the required contents, which must be maintained. Thus, the failure rate should be blamed on the teaching-learning method and the context surrounding the students.

If knowledge is a desirable well-being, the barriers to the enrolment and the conditions to continue a course should not be hardened. Accordingly, to enhance the academic yield we should focus on the improvement of the teaching-learning process. Another underlying issue is to balance the maximum academic yield in such conditions and the associated cost of educational innovations to effectively enhance it.

Hence, taking the present situation as the starting point, we pose the following improvements:

- More motivation and better results are required; this might be achieved if students could have closer contact with professional practice.
- More supervised laboratory seminars where students could develop their own experiments are needed.
- Additional examinations organised by the faculties should test the initial level of knowledge of freshmen.
- In case the freshmen do not reach the required level, they should undergo an introductory course.

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