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Una experiencia práctica del uso de aprendizaje activo y técnicas docentes innovadoras en una asignatura básica de ingeniería
A hands-on experience of the use of active learning and some innovative teaching techniques in a basic engineering subject

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Abstract

Este artículo presenta la experiencia del uso de un conjunto de técnicas de aprendizaje combinadas en el contexto de una asignatura de segundo curso de ingeniería (campos electromagnéticos), prestando una atención especial al punto de vista de los alumnos y a su percepción de utilidad para ellos mismos. Entre las técnicas usadas hay algunas más tradicionales como clases magistrales o resolución de problemas a cargo del profesor, y otras más innovadoras como videos, pruebas de un minuto, resúmenes orales diarios y trabajo en equipo en el aula. Las escuelas de ingenieros han sido tradicionalmente poco dadas a cambios radicales en sus métodos de enseñanza, pero al mismo tiempo, la evolución actual de los requerimientos de la industria, las hace especialmente conscientes de la necesidad urgente de nuevas ideas en el campo de la docencia, colocándolas en una posición de liderazgo en el desarrollo de nuevas técnicas de enseñanza. Este trabajo pretende ser un paso decidido en la dirección de un cambio positivo de los estudios de ingeniería.

Abstract- This paper presents the experience of trialling a variety of combined learning techniques in the framework of a second-year engineering subject (Electromagnetic Fields), paying special attention to the point of view of the students and the usefulness perceived by them. The techniques include both traditional ones such as lecturing and problem solving by the teacher, as well as more innovative ones such as videos, minute papers, daily summary presentations and in-class team working. Engineering schools have been traditionally reluctant to implement profound changes in their teaching techniques but at the same time, the current evolution of the requirements of the industrial sector makes them aware of the urgent need for new ideas in the field of teaching, and so inevitably gives them a potentially leading role in the development of new classroom techniques. This work is intended as a firm step in the direction of positive change for engineering studies.

Keywords: aprendizaje activo, trabajo en equipo, aprendizaje entre iguales
active learning, teamwork, peer-learning

1. Introduction

Education and thus teaching is undergoing a radical change worldwide. The availability of information on the internet, the automatization of intellectual tasks that could not previously be carried out by machines, and the foreseeable evolution in the requirements of industry will without doubt mean that future generations are going to have jobs significantly different from those being done at present. A detailed and lucid description of this particular moment can be found at Ken Robinson's "Creative Schools" [Robinson, 16].

Skills such as written and oral communication, creative reasoning, teamwork, autonomy, and active learning will soon become the flagships of what will be understood and required as university education. The acquisition of these abilities requires a modification in teaching activities beyond traditional expositive lectures. This change affects all levels of education, from kindergarten to company training, and is taking place in an informal way. Some teachers are piloting new techniques with students of different ages,

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but the pace of the implementation of definitive and sustainable changes is slow [Koeslag-Kreunen, 18]. Furthermore, the adaptation of students at higher levels requires time and sometimes may bring confusion to classrooms.

It would seem logical that changes should be implemented starting at lower levels; however, uncertainty about the speed of change at higher levels is blocking progress lower down the system. Universities should play a key role in this change. First, they should encourage teachers in all levels of education to experiment with new learning techniques. Secondly they should analyze the effect of these changes by means of informed and well organized research. Thirdly, universities should implement and disseminate the changes without delay once they have been shown to be effective. The change will be more operative and make more sense if it is implemented from the bottom up, but ideas and analysis of results should come from a top-down approach. Research in this field should be effectively led from universities.

There is a need for practitioners to experiment with new techniques that can also be used in university classrooms. One of the paradigms that can advantageously guide this research is active learning [Biggs, 99], [Freeman, 14], which has been widely recognized as an effective teaching method. In the field of STEM subjects, some particular techniques, such as peer learning, have been extensively trialled, for example by Eric Mazur [Mazur, 97], [Crouch, 01], and have obtained interesting results.

This paper presents the experience of testing out a variety of techniques in the framework of an engineering subject, paying special attention to the point of view of the students and the usefulness that they perceive the activity to have had. Following the classification of [Ruiz-Primo, 2011] this work mainly focuses on Conceptually Oriented Tasks and Collaborative Learning Activities, leaving out Technnology (Lab work) and Inquiry-Based Projects. Previous studies have shown that active methods are perceived as more useful by students [Magana, 18] and also that perceived usefulness is also connected with an involved role of the teacher [Carpeno, 11]. It is not the intention of the author to present detailed or definitive conclusions, but rather to take a firm step in the direction of positive change. Engineering schools have been traditionally reluctant to change but at the same time, the current evolution of the requirements of the industrial sector has made them aware of the urgent need for new ideas in the field of teaching and places them in a leading position in the movement towards this new education.

This paper starts by presenting the context of the experience, including the basic schedule of a lecture. Then, the activities that have been used are briefly described. After this, the results of a survey assessing the usefulness of the activities as perceived by students is shown. Finally some conclusions are drawn and proposals made

2. Context

This paper presents an experiment carried out for two years in the subject of Electromagnetic Fields at the ICAI School of Engineering at the Pontifical Comillas University in Madrid. Electromagnetic Fields is a mandatory subject in the second year of the Bachelor's Degree in Engineering for Industrial Technology. It includes sixty hours of lectures and no laboratory classes. It provides a comprehensive introduction to electromagnetics, covering basic phenomena in the areas of electric fields, magnetic fields and electromagnetic induction.

This kind of subject is traditionally taught by combining lectures, with only sporadic participation by students, with practical sessions based on problem solving, again carried out mainly by the teacher. An alternative way of addressing this subject will be introduced here. It is important to point out that no changes have been made in the content of the subject, which is mainly oriented towards a conceptual understanding rather than a numerical approach. This makes the subject difficult for students because they have to develop "understand why" skills rather than "how to do" ones.

A. Lecture structure

Lectures were organized using a basic structure what was used almost every day, with some changes to adapt it to the pace of each group. It consisted of:

- A quick summary (one minute) of the previous class made by a different student each day and completed by the teacher if necessary.
- A theoretical explanation of the content that was going to be taught the lecture, which lasted around fifteen minutes.
- A basic example developed by the teacher with immediate application of this content.
- A more complex problem exercise to be solved by the students. Depending on the day, it was solved individually, in pairs or in fours.
- A pooling of the work done.
- A five minute paper to check understanding of the concept.

Additional work was suggested to the students to be done outside the classroom, following a work plan that was available in Internet:

- Further reading from the textbook.
- A worksheet with problems to go deeper into the ideas developed in the classroom. For most of these problems, the results were given (but no information was provided about how to actually find the solution).

Students could ask the teacher for advice about solving these additional problems either in person, or through question and answer forums on the internet

3. Description

A number of techniques were trialled, including daily lecture summaries, short teacher explanations, teamwork, videos, five minute papers and cooperative problem solving.

The different techniques have been sorted following how useful students considered them. Some of them can be regarded as "innovative" techniques and others are more classical. It is interesting to see how the combination of both worked well.

None of the activities presented are groundbreaking but the experience of their combined use and the comparison of the perceived usefulness provides some interesting insights, and can also serve as inspiration.

A. Videos

The theoretical introductions of some classes were recorded in short videos around fifteen minutes long. The students could use these to review classes.

Twice during the course, a flipped classroom structure was used: students were asked to watch the video before the lecture and an explanation in class was not given. Most of the students said that they had seen the video and apparently they did, as the number of accesses registered was similar to the number of students in each group. No additional check was carried out, as is suggested by those who use this kind of classroom structure.

Most of the accesses to videos that were not used to flip the class structure took place in the days following the class. The contents of the video were presented in the classroom and again in the days before exams.

Videos were recorded using Mirillis Action software. They included slides, similar to those used in the classroom, and a small window with the teacher explaining them as shown in Figure 1.

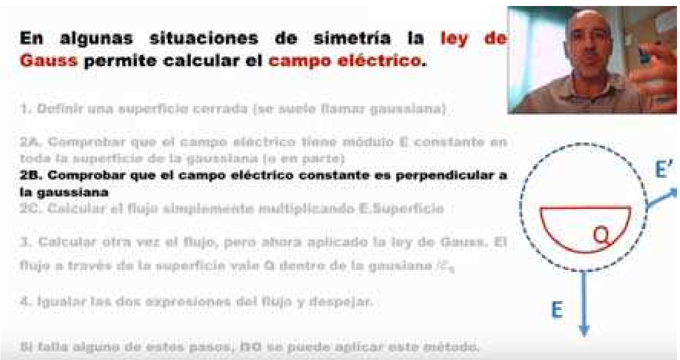

Figure 1: Sample of a video lecture (in Spanish).

B. Five minute paper

Five minutes paper (or minute paper) is an assessment technique commonly used by a number of university teachers, described for example at [Angelo, 93]. In our case, one or two simple questions (often, multiple choice questions) about the material covered were asked to make students aware of their level of understanding of the main ideas discussed during the lecture. They were done using the Moodle platform or sometimes Kahoot (most of the students used the phone to do the exercise, some tablets or laptops), and sometimes the answers were analyzed in class (with the use of a bar diagram to show the frequency of answers), especially when a wrong answer had been chosen by a significant number of students. This happened frequently, as question were carefully chosen to address common mistakes or subtle details of the theory.

These minute papers were offered to the students as formative assessment and they did not have an impact on the final mark, although the teacher could access the answers of individual students.

C. Problem sheets

The use of problem sheets is a very common technique in technical subjects. They were made available on the internet, one per chapter, and they included the solution for each problem. The problems on the sheets were focused more on the quality of problems than on the quantity. Around fifty problems in total were included in these sheets. Some problems were solved in the classroom, but most of them were left for the students' personal study. Questions about these problems were answered by the teacher before or after the lectures, through appointments with the students or using internet forums.

Students were not enthusiastic about using question and answer forums at the beginning of the term, but they became more popular during the last weeks. It is interesting to note that students never answered questions posted by their classmates. In general the number of questions was low and thus we cannot draw definitive conclusions about this technique. We intend to use it again in the future, encouraging students to use forums as we consider them a useful tool. For the present, whether they are useful from the point of view of students remains an issue requiring further trial and research.

D. Exercises done by the teacher

This is another classical way of working in the classroom. In our case, although the teacher was the person who developed the solution to the problem, this was done with a high level of interaction, with students continually being asked about the next step, being required to solve some parts of the problem or to propose alternative ways of finding solutions.

E. Individual work and pooling

This is an active learning technique which is easy to implement. A significant problem connected with the content is given to students, who then have some time to think about it and try to come up with a solution. Most of the questions were of a qualitative type. ("If this coil is moving towards the magnet, in what direction is the current that appears in the coil moving? Clockwise, anticlockwise or zero?") Students were then asked to raise their hands to indicate which solution they thought was correct. Students representing the different alternatives were invited to justify their choice. There was then a second raising of hands in which students again had to select which solution they thought was right. Most of the time results were much better in this second round.

This way of working requires the teacher to be very sensitive with students; otherwise it is very difficult to make them participate, especially when they think that they may not have the right answer.

F. Daily summary (expert of the day)

A brief summary (just one minute) of the previous lecture was made by a different student each day at the beginning of the lecture. He or she was called the "expert of the day". They were asked to explain two or three key ideas, without using equations if possible. The teacher completed the summary with comments, remarks and corrections if necessary.

Once the students got used to this way of starting the class, they liked it. They had to prepare it only once during the semester and the round of applause after the short talk provides energy for starting the lecture. The summaries were also a nice excuse for introducing the content of that day's class.

At the end of each chapter, the teacher made two or three key points from each lecture available on the internet to help with exam preparation.

G. Slides

A set of one to six slides was used each day to introduce the theoretical content of the class. These slides were available for the students on the internet. They were also the same slides that were used in the videos to explain the theoretical content.

H. Teamwork

This is another interesting active learning technique. A significant problem connected with the content that has been presented is given to students, who are given minutes to think about it in g, trying to come up with an answer.

It is possible to proceed with a raising of hands as was described for the pooling after students have worked on problems individually. Another interesting alternative is to propose that those who have found out the right answer explain it to people in the same team or in other teams. The degree of focusing and the energy that is developed when a student explains something to a colleague is surprisingly high, and sometimes they continue with the explanation even when the bell has rung and the class is over.

An activity that was tried once (known as "the jigsaw") was to divide a problem (a demonstration) into six steps. Several groups were formed and each worked on a different step of the demonstration. After the discussions, groups were rearranged so that each group included "representatives" of all the six steps. Each group had one week to "assemble" the whole demonstration, write it up and hand it in to the teacher. Conclusions about this activity are pending, as it was not done with sufficient time to allow every group in the first stage to arrive at appropriate results, and the second stage was not interesting enough to create a good work dynamic.

I. Work plan

A work plan was provided for each chapter. It included, for each class day, a description of the content: the slides that were going to be used, the paragraph in the books that were related to the lecture content, the problems that were going to be solved and those which were going to be given to students to solve (the number of the problems on the worksheets).

J. Assessment

As this subject was taught by different teachers to different groups (eight in total), and the approach presented was only used for two groups,assessment was carried out in a traditional way: one preliminary exam that accounted for 10%, a mid-term exam (30%) and a final exam (60%). Exams consisted of a set of problems requiring more qualitative reasoning than mathematical computation.

The active learning approach that had been used for some of the activities would require that a part of the grade (10 or 20%) was obtained by means of participation, i.e. five minute papers and others. This change has been proposed for the next academic year. Even when they were not graded, some of the activities show a great potential for learning and they are perceived as useful by students, which is a key factor in their attitude and motivation .

4. Results

A. Students survey

The results of a survey answered by students is presented. 60 out of 94 completed the survey. All the previously described activities were classified as very useful, useful, not very useful or useless. Table 1 shows the results.

First of all, it should be noted that the average mark for the overall class is high: over 3, that means "useful". This can be interpreted as meaning that from the point of view of students, the combination of a number of classical and new techniques is appropriate.

The activities that were considered most useful (videos, five minute papers and problems sheets) are connected with the student's autonomy, which is a good sign.

Problems resolved by the teacher also received a high mark. However, when students were specifically asked if they thought that the explanation of problems solely by the teacher without students being questioned was useful for learning, a clear 68% thought that they were not, with only 12% expressing the opposite view. This result suggests that this activity (teaching plus questions to students) is valued in the active learning version.

Daily summaries and slides, though seen as valuable, were not considered as useful as the previously mentioned activities. And finally, teamwork and the work plan were

Table 1: Results of the survey

	Very useful	Useful	Little useful	Useless	AVERAGE
	4	3	2	1	
Videos	41	17	2	0	3.65
Five minutes paper	37	19	4	0	3.55
Problem sheets	29	27	3	1	3.40
Exercises solved by the teacher	27	27	6	0	3.35
Individual work and pooling	21	34	5	0	3.27
Overall class	15	35	10	0	3.08
Daily summary	14	28	14	4	2.87
Slides	12	25	17	6	2.72
Team work	10	25	22	3	2.70
Work plan	7	27	16	10	2.52

the least popular features of the course in terms of their usefulness. In the case of teamwork, the mark is still high (2.70), but it suggests that some aspects of the activity should be reviewed. The first of these is the furniture in the classroom. Lessons were given in a class with classical heavy desks without much additional space around them. They were moved for teamwork. The students were also specifically asked if they thought that moving the tables to work in groups was worthwhile (they could also work in groups in the classical classroom configuration with some of them turning their backs). In this case 25% clearly thought that it was not worthwhile whereas 29% thought it was.

B. Is there any effect on students' grades?

For the sake of completeness, the students' grades were compared with those of other groups in which different learning techniques had been used. It was found that the differences had no statistical meaning.

5. Conclusions

This paper has presented the experience of using different teaching/learning techniques, analyzing their usefulness as perceived by students. As a result of his experience in this subject and others that are not presented herein, the author firmly believes that the use of innovative techniques, in combination with those of a more traditional nature, has a generally positive effect both on teacher and student motivation. Of course, not every technique is suitable for any teacher, student or situation. The art of teaching requires that one has at one's disposal a variety of resources and the ability to be able to decide at each moment which one is the most appropriate for fostering learning. There are a large number of techniques available for different kinds of situations and, having been trialled, the experience has been presented in this paper. The work of a teacher includes having at his/her disposal as many techniques as possible and designing different learning situations.

Among the techniques that were used, videos, minute papers, and problem worksheets were particularly appreciated by students. Our opinion is that this is connected with the fact that they gave them independence, and motivated them to work autonomously.

Explanations given by the teacher were also valued. This suggests that eliminating them completely, at least in the first stage of innovation, might not be a good idea.

Individual work and pooling is also considered useful by students, but less than the techniques referred to above. Nevertheless, from the point of view of the teacher, direct interaction with the students is an invaluable source of information and should be used as much as possible.

Teamwork is less popular with students. One practical difficulty was that no appropriate furniture was available and changing the configuration of the class was problematic. There is a need for special furniture in order that students can take advantage of all the potential of teamwork.

The effectiveness of any of the techniques described is very dependent on the context, so teaches need to select wisely from other people's experience and not simply try to replicate what they have seen described. In our school of engineering there are teachers meetings to discuss different aspects of innovation that has been taking place for more than twenty years on a regular basis. In this respect, the support of the academic authorities is clearly crucial for the development of any kind of innovation.

Finally, in this experience, no changes in the form of assessment were implemented for practical reasons. Obviously, any innovation in education requires a coordinated adaptation of assessment which is consonant with agreed objectives.

Further and continuous trial-and-error work is required if we wish to be able to contribute from universities to the change that education requires.

Thanks

Many people have given ideas and supported this work and I am grateful to all of them. Special thanks to the rest of the teachers from "Campos Electromagnéticos": for accepting changes and alternative methods. Thank you also to Pablo García and the rest of the management of the school of engineering, who are promoting the adaptation of classrooms for teamwork and have an open and proactive attitude towards innovation. I also want to express my gratitude to Antonio Muñoz and Nacho Gonzalo, who regularly organize our "innovation group" meetings and with whom I am currently cooperating. This group is creating

increasing interest amongst teachers, and we are working to make positive use of all this creative energy.

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