Joining together theory and practice in the classroom for electrical engineering undergraduates: the large-scale portable laboratory [H1]

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Abstract [ABKWH]

Electrical engineering teaching requires a combination of theoretical and practical lessons which are, in general, separated for practical reasons. The correct balance between theory and practice is not easy to define and it is a common impression that theory has gained relative weight when compared to laboratory. Laboratory sessions are more expensive than large audience classroom lessons and the group size for laboratory work has to be small. Expensive equipment makes also unfeasible large scale laboratories and laboratory facilities are very often neither appropriate nor comfortable for theoretical lessons. Thus, we describe a proposal to bridge the gap between theoretical explanation or exercises and practical application in a laboratory: the large scale portable laboratory. This temporary laboratory is deployed and collected again in a conventional classroom in few minutes. It allows, with safe voltages and currents, to illustrate and immediately applicate theoretical concepts or to show some phenomena and explain it later by theory in a discovery attitude. This laboratory has some physical limitations (voltages, currents, power, cost and weight of elements) and, by no means, intends to replace practical sessions in a full equipped electric teaching laboratory. It is mainly a tool to connect experimental observations and theoretical explanations during students learning. A complete session with this laboratory will be described and the obtained results will be presented. As a general result, involvement of the students is dramatically increased. Besides this training of students helped in earning time for electric laboratory practical sessions. It also provided good results in a test about the contents of the lesson. Some difficulties such as the preparation time for such mixed theory and practice lessons, and the spent time during the session are also discussed.

Introduction and context

In Electrical Engineering Education, theoretical lessons and laboratory sessions are generally separated for practical reasons. Laboratory sessions are more expensive than large audience classroom lessons and the group size for laboratory work has to be small. Expensive equipment makes unfeasible large scale laboratories. Besides, laboratory facilities are very often neither appropriate nor comfortable for theoretical lessons. Recently, Judge has presented a very interesting attempt to work in large-scale laboratories for teaching electronic and electrical engineering to first year undergraduate students [1]. But this is not a general practice. As a result, there is an artificial separation between theory and practice which is not suitable, especially for the engineering skills. It is generally accepted that engineering is in its origins a practical discipline but today with a wide content of theoretical contents [2]. Thus, the balance between theory and practice is not easy to define and it is a common impression that theory has gained relative weight when compared to laboratory. This is, however, an artificial separation but it should not be understood as a competition between “theory” and “practice” but rather as a cooperation between both methodologies. For example, Giacaman and De Ruvo describe a strategy to bring together theoretical and practical sessions in the field of programming [3]. Practice is not necessary coming after theory. If a discovery attitude is preferred, practice can be done before theoretical lesson. Or, in a more standard method, students apply or check theoretical concepts during the practical lessons. According to this, the aim of our work is to bridge the gap between laboratory and theoretical sessions by mixing practical lessons in the classroom

Of course, presentation of theoretical concepts and rigorous deduction of theories are always required. All the courses shall not be reduced only to practical lessons, but theory is best understood and illustrated if it is immediately connected to a practical experience (as already stated in [4]) or even preceded by practical observations. Teacher’s practical demonstrations in the classroom can help in this task [5][6][7], but student direct experimentation with concepts and practical elements leads to better results in understanding and learning [8][9]. A possible solution is to use computer simulation tools which can be easily introduced in the classroom. In fact, in some Engineering fields, computer simulation of practical situation has taken a dominant place in the practical sessions. These software tools are of paramount importance for students, since they will have to use them in their future, but direct contact with physical experiments cannot be replaced by simulation instruments, especially during the first courses. Our objective could have been achieved with a student’s version of simulation software, but a real practical experience was preferred to reach a mature concept of electrical circuits before using abstract simulation tools.

Our work is aimed to second year undergraduates of three different degrees at the Polytechnic University of Valencia (Spain): Civil Engineering, Public Works Engineering (similar to Civil Engineers but with different professional responsibilities) and Chemical Engineering. In all these three bachelor’s degrees, the students are not especially focused on electrical engineering concepts. Besides, in all of them, there has been an important reduction in both the number of theoretical and practical lessons for the electrical engineering teaching. In the case of practical sessions, the reduction reaches in some case 70% and for the theoretical lessons it is close to 50% in all the cases. However, in the last degrees remodeling (2011) the total number of ECTS (European Credit Transfer and Accumulation System) and thus the teaching hours was increased for an equivalent professional qualification in all of these three degrees. Furthermore, some optional courses in electrical engineering were removed from the curriculum. As a result, students have only a four-month course of electrical engineering in their curricula with 24 or 30 hours of theoretical lessons and 7.5 or 8h of laboratory lessons. After this course, no additional electrical engineering course is given to students, even if they pursue to the master degree, in the case of Civil and Public Work Engineering. This context is important for the present work since the relative weight of the electrical engineering has been dramatically reduced as seen by the students (although graduates keep their previous professional responsibilities). That creates a general opinion of secondary importance of electrical engineering learning.

Moreover, in these bachelor's degrees, students are very often not familiar to electrical circuit basis or electricity physics. The residual importance of electrical engineering in the curricula makes difficult for the students to understand the relevance of electrical engineering for their future. Although motivation is of great importance for students success in engineering and electrical engineering [8][10], in our case, it is limited because of: 1) they do not understand why they should study electrical engineering (so different from mechanical engineering, structural calculations, chemistry, etc.), 2) the subject is not connected to other courses in their studies and 3) they are not familiar with electrical concepts.

Since, in the short term, it is not possible to increase the total amount of electrical engineering lessons, especially laboratory sessions, we are working on a proposal of mixing theory and laboratory sessions in the classroom by means of the deployment of a portable laboratory in the classroom during the time allocated to the lesson. At the Polytechnic University of Valencia, students normally do not move from one classroom to another for theoretical lessons. They stay at the same classroom and teachers move from one to another. Thus, teachers do not have a specially designed classroom for lessons which always take place in standard classrooms. The proposed solution (what we called the large-scale portable laboratory) for mixing theory and laboratory session in the classroom requires building and collecting an electrical engineering laboratory in a conventional classroom during the lesson. That needs to solve some issues: 1) deployment and collection of the laboratory should need minimum time, typically, less than 10 minutes, 2) laboratory has to be safe, 3) the total weight of the equipment to be moved to the classroom has to be as low as possible, 4) no expensive additional equipment should be needed, only available laboratory equipment such as multimeters, voltage sources or safety cables should be employed.

All the parts and procedures of this laboratory will be described as well as a first experience in a classroom and the obtained results.

Portable laboratory description

The structure of the classroom laboratory is based on the distribution of an individual small low voltage low current source on each table of the classroom. It consists in a small box (10cm × 10cm × 5 cm) with 5 female banana connectors (see figure 1). Depending on the experiment different combination of connectors will be used. For DC or AC circuits the red and black one can be used, for 3 phase circuits the red, black and green will be used for the phases, the blue one for the neutral conductor and the yellow for the ground conductor. Voltage will be kept always below 24V and current limited to some hundreds of milliamps, thus safety requirements are met. The ground conductor in such situations is not really necessary but it helps in teaching to students its importance.

Figure 1. Right: individual voltage source (d-sub 9 connectors are on the sides of the box). Left: general distribution box with the protection fuses and the d-sub 9 connectors.

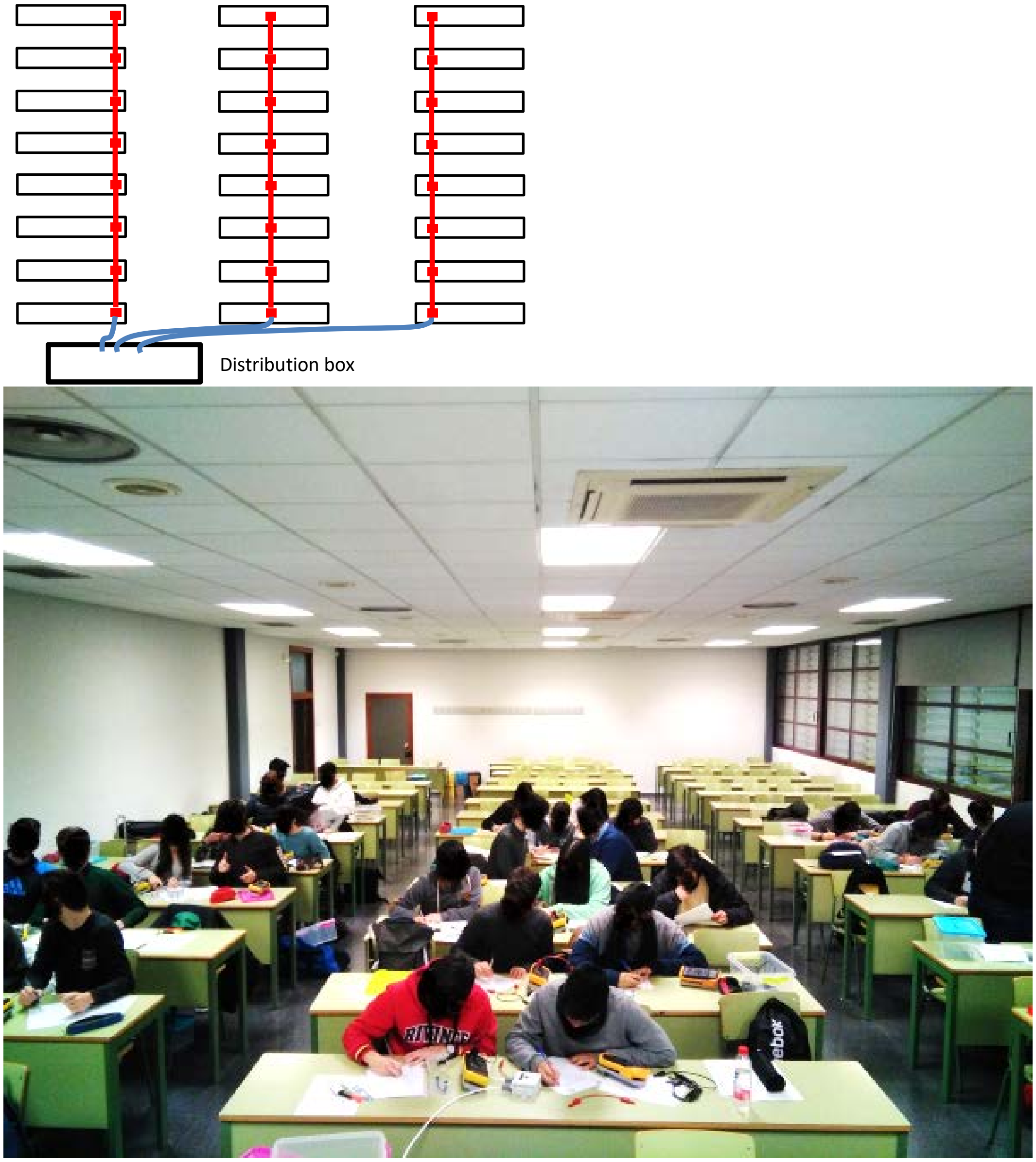

Figure 2. Table distribution and general view of the classroom.

Students will work in pairs or trios as a maximum. The classroom is divided into three columns of tables (see Figure 2, left) with a maximum of 8 rows in each column. Each individual voltage source of row “n” will be connected to the voltage source of the table in row “n-1” by means of a 1.5 m cable with d-sub 9 connectors. This cable is inexpensive and avoids connection problems. 2 wires are used for each phase in order to increase the total current to be carried. The first row will be connected to a general distribution box in a central table (see Figure 2, right). This general distribution box can feed up to 5 table columns and it is connected to a low voltage 1A two output DC source.

During a lesson about DC voltages, as described below, a voltage source was connected between the red and black connector and the second one to the green and black connector. Thus, the distribution box can provide a DC voltage source to students. For other configurations as, for example, an AC source, a 220/12V transformer will be used to produce safe low AC voltages. For a 3-phase AC voltage source a low power inverter connected to three 220/12V transformers (to reduce voltage and filter harmonics) and a 3-phase 1A circuit breaker can provide the voltage system.

Figure 3. Image of the toolbox for each student group.

A tool box is given to students (Figure 3). It contains the individual voltage source, the 1.5 m long cable to connect to the "n-1" row voltage source, 8 banana cables, 2 multimeters and 3 resistors (55 Ω, 110 Ω, 12Ω) in 3 individual boxes with 2 banana female connectors. At the end of the session, instructions are given about how to tidy up the toolbox again. They bring it again to the trolley where they collected it. This toolbox, of course, should be modified for each different lesson. The trolley was a flat platform of 1m x 0,5m where toolboxes were arranged in 5 layers of 5 toolboxes, leaving some place for a larger teacher's toolbox containing the power source, 5 longer connection cables and spare parts. It was easily handled by one person from the laboratory to the classroom (care has to be taken about stairs and elevators or the width of doors during the itinerary which should be carefully chosen).

In the following paragraph we will describe a lesson about DC circuits which has been carried out in the classroom.

Practical implementation of a DC circuit lesson

The first topic of this practical implementation of a DC circuit is students' safety and equipment safety. A double channel DC source with a maximum voltage of 30V and a maximum current of 1A per channel was used. However, voltage was limited to 15V thus avoiding electric shocks. Besides, no hot spots can be produced with the chosen resistance and voltage values. With the current limitation, any short-circuit will not be dangerous and could be detected by some ammeters at the source. This is necessary since, due to the large amount of students, the teacher will not supervise the circuits individually. This is an important difference when compared to the power laboratory practical lessons where voltages and currents could damage equipment whereas electric shocks to students are avoided by protection systems. In the large-scale portable laboratory no electric shocks or high currents can happen with the DC source limitations. Some bad connection (e.g. an ammeter in parallel with the voltage source) will be detected because of an anomalous high current in a row. Then this row will be supervised until detecting the bad connection. However, when asking to students in a row if they find an unexpected result it is easy to quickly localize where the problem was. Other bad connections (e.g. a voltmeter in series with the circuit) will not be detected by high current. Thus, it is convenient to regularly comment results and ask students if they all have similar results.

In this example, the lesson was carried out during a session of 3h (normally a 3h pure theory session) but it could be split into 2 sessions of 2h, probably a better solution. The number of students was 40 working in pairs.

The lesson contents were the following (corresponding circuits are shown in Figure 4):

1. Distribution of the tool boxes (*duration: 5 min*).
2. Short presentation of the laboratory and description of all the elements, especially the multimeter and its use. Connection of all the individual voltage sources and the general distribution box (*duration: 15 min*).
3. Verification of the Ohm's law. It was carried out by means of the resistances and the variation of the voltage level. Voltage and current were measured in a resistance while the teacher modified the applied voltage E_1 (Figure 4a). (*duration: 15 min*).
4. The series and parallel association of resistances was also verified with the ohmmeter function and by measuring current and voltage in different resistance associations (Figure 4b). This was done in a discovery or investigation context what means that the circuits were presented and the students found the results before explaining the series and association rules for resistances. (*duration: 15 min)*
5. After this there was a theoretical explanation about some strategies to use equivalent and simplified circuits in order to solve a more complex one (*duration: 20 min*).
6. A first circuit made of a single voltage source and 3 resistors was analyzed theoretically making a prediction of current and voltage across all the resistors (Figure 4c). Verification was carried out with an ammeter which measured the current at the source and then, by moving the voltmeter, all the voltages were verified. It has to be noted that voltage of the source was measured before the calculations since there was a drop of voltage and each group had a different value of voltage source. Currents were indirectly measured from the voltages and the Ohm's law. (*duration: 25 min*)
7. 15 min break.

8. The theoretical lesson continued with other methods such as the mesh calculation for solving circuits. (*duration: 20 min*)
9. A circuit made of 2 voltage sources and 3 resistances in a 2 mesh circuit was built (Figure 4d). Voltages at the sources were measured by each group then, voltages and currents across all the resistances were calculated. Verification of the results was done by measuring voltages across all the resistances. Currents were indirectly measured from the voltages and the Ohm's law.
10. Students tidy up their toolbox and bring it to the trolley. (*duration: 10 min*).
11. Short test about the lesson and survey to students. (*duration: 15 min).*

The strategy was to continuously mix theory and direct experimental verification as well as keeping the students active during the lesson by experimental manipulation of circuits. At the end of the lesson a short test ("a one minute question" [11] but with 5 questions and extended to 5 minutes) was carried out by means of the online tool of the University (Sakai project). Special attention was given to the multimeter configuration and use. Some results of measurements and calculations in both circuits were asked.

Finally an anonymous students' survey about the lesson method was also carried out.

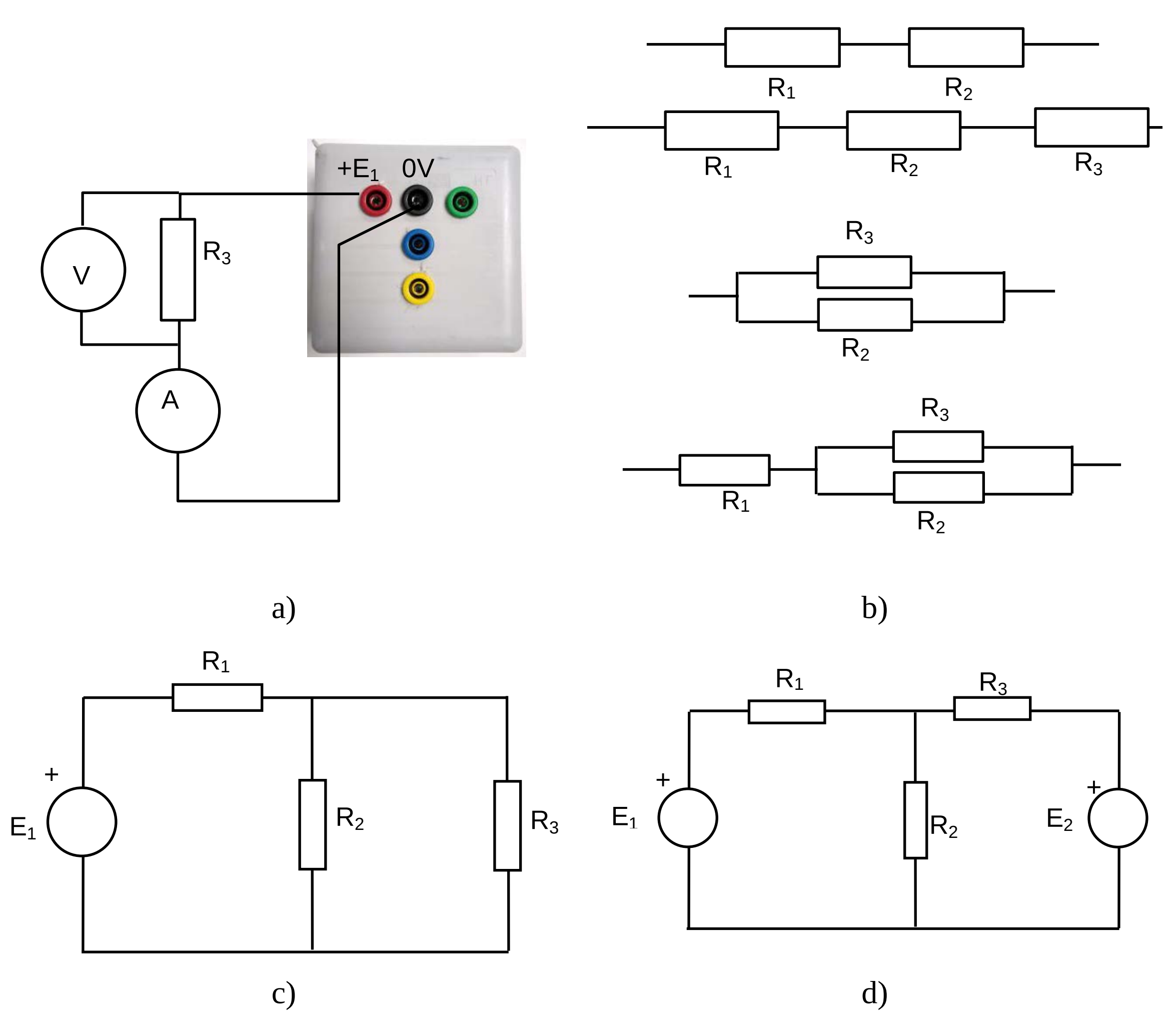

Figure 4. Circuits built during the lesson.

Analysis and further improvements

The experience of mixing theory and practice in the classroom was very positive. Time for building the laboratory in the class was about 10 minutes but it can be easily reduced once the students get used to the procedure. Collection of all the elements of the laboratory also took some minutes and it was done during the short test at the end of the session.

There were some good practical results. For example, the explanation of the multimeter use earned some time for pure laboratory lesson which are shorter and scarce, thus leaving time for other purposes of for a slower rhythm in practical power laboratory.

Students were very active and had a very positive attitude during the lesson. Their comments highlighted that the method was pleasant and they enjoyed the application of theory and practice simultaneously. Some found it encouraging with the course. On the negative side, the main drawback is the time limitation and the availability of the teacher due to some circuit revisions.

Some of the comments showed from the students' side a good degree of responsibility and reflection about their own learning [12]. The survey (see figure 4) also provided good scores over 10 for items like increasing involvement in the course (9), taking pleasure in the course (8.88), satisfaction with the methodology (9.2), or recommending this methodology for other lessons (9.6).

Figure 5. Statistical results of student's survey.

On the other hand, the short test about the lesson contents delivered very good results, a mean score of 8.4 over 10 showing good comprehension of the topic. Questions about the use of the multimeter obtained a 72.5% of good answers, questions about series-parallel association reached a 92.5% and questions about circuit 1 where correct in a 87.5% whereas questions about circuit 2 only obtained 47.5% of good answers. This last percentage was due to the fact the circuit 2 could not be completely built experimentally for schedule reasons and it was theoretically analyzed (that is also one reason for the negative students' comments about the need for more time).

Although the experience was mainly very positive, some practical difficulties were found. First of all, there was a significant drop of voltage in the cables from the first to the last row. Thus, students' experimental results have some scattering making it difficult for the automatic test at the end of the lesson to check correct answers. This drop of voltage will be solved in the future by increasing the cross section of the connection cables and reducing contact resistances.

There was also some ambient noise due to students' conversations during practical parts of the lesson which made sometimes difficult for the teacher to give general indications. We also found a small amount of connection mistakes in student's circuits that required some extra time for solving them. One person from the laboratory staff assisted the lesson to help in reducing this time. At the end, the 3h lesson was slightly short to reach the objectives at a convenient rhythm.

Additionally, building of all the material required some work since there is no commercial available system for such large-scale portable laboratory in the classroom. And preparation of the material for each classroom session requires some time to gather all the material from the laboratory. In our case, this session was not compatible with a pure laboratory session at the same time since most of the material was required for the large scale classroom session (especially, multimeters).

Conclusions

This works proposes a way to bring together theory and laboratory sessions for first courses undergraduate electrical engineering teaching in large groups (40 students and above). The capacity of this portable laboratory is up to 80 students working in pairs, although it has not been tested in such a large group.

Once this methodology has been successfully tested, it would be positive to involve more colleagues in similar courses (namely electronics but also others electrical courses) in order to make it a regular methodology for lessons. Students could be more familiar to the methodology, helping in making work more efficient. But, this kind of mixed theoretical and practical courses, by no means, will replace a laboratory session were higher voltages and currents or heavier equipment (e.g. motors or transformers) can be handled. As long as there would not be an available large scale laboratory comfortable for theoretical lessons, separation of theory and practice will be necessary. The total amount of laboratory sessions should be kept or increased irrespective of the methodology used in the classroom. This large-scale laboratory is aimed to fill a gap between pure theory and pure practical lessons but it should be considered as an additional methodology and not a substitute of practical lessons.

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