HANDS-ON TEACHING AND ENTREPRENEURSHIP DEVELOPMENT

Marcos Azevedo da Silveira (marcos@ele.puc-rio.br), Mauro Schwanke da Silva, Christian R. Kelber and Manuel R. de Freitas, Departamento de Engenharia Elétrica, PUC-Rio, Rua Marquês de São Vicente 225, 22453-900, Rio de Janeiro, RJ, Brasil

Abstract - This paper presents the experiment being conducted in the Electric Circuits II course (ELE1103) at PUC-Rio's Electrical Engineering Department since March 1997. The experiment was held in both the fall and the spring semesters of 1997.

The basis for the experiment was concurrent teaching methodology [1], to which the principles of entrepreneurship development were added. Concurrent teaching methodology includes hands-on activities, and this experiment served as a test lab to improve it. Entrepreneurship development is one of the topics suggested by the National Science Foundation (NSF - USA) and by the REENGE Program (CAPES/CNPq/FINEP - Brazil). This topic has been included in the activities of the Scientific and Technological Center (CTC/PUC-Rio).

This work presents the results of the experiment and some of the ideas behind it. It is original because it strongly relied on the use of hands-on practice after its fundamentals and its consequences were understood. It is a success story because the experiment's objectives were reached.

The course in which the experiment was conducted includes a traditional teaching/learning activity. There is a syllabus with specific topics to be presented in lectures, plus weekly lab sessions. This characteristic of the experiment seems to point to a possible extension to other conventional engineering courses.

The paper presents an analysis of the specific characteristics of the rites of passage from the lower to the upper division of Electrical Engineering students at PUC-Rio. The contents of the courses in this transition, as well as the study habits of the students, are discussed. Also included is a brief diagnosis of the situation previous to the experiment, along with remarks and complaints from the instructors of the courses that followed.

The major points of the experiment methodology may be summarized as:

- *Relate to the students in a mature manner. The rules of the game were previously stated by the instructors and were followed throughout the course;*
- *Stimulate student involvement in the activities by showing a deep involvement on the part of the teachers and instructors;*
- *Relate to the students on a very specific and individual basis;*
- *Develop a new method of relating concept to experiment by stimulating students to build the concepts (those strongly related to physical situations) as they experiment in the lab;*
- *Propose real-world problems;*
- *Suggest industrial applications and professional quality;*
- *Specify the formal leadership for each project team;*
- *Request minimum standards for the presentation of projects. For example, for the oral presentation students were expected to use more formal language, dress less causally and include a Power Point*-type slide show;*
- *Have teams compete with one another. Students were graded according to the performance of each team vis-à-vis all other teams;*
- *Evaluate the results with the use of external referees, some of them from companies active in the market.*

In the work, the details of the experiment will be discussed. Some generalizations will be suggested. A final evaluation will be presented, including comments from students who took the courses.

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***Key Words**: Engineering education, hands-on teaching, electrical engineering education*

Introduction

This paper presents a teaching experiment conducted in Course ELE1103 — Electric Circuits II, at PUC-Rio's Electrical Engineering Department, during the two terms of 1997, which tested and developed hands-on teaching methodology — more precisely, concurrent teaching methodology as set forth by [1] and [2]. The paper is both a report of an experimental test of the ideas proposed in the two articles and a partial presentation of the origins of these ideas.

The originality of this work lies in its refinement of the practice of hands-on methodology on the basis of a more thorough understanding of its foundations and effects, in addition to a description of an experiment that achieved its intended teaching effects. In this case, the methodology was applied to a traditional discipline, with a well-defined content and conventional theoretical lectures, which is an example of a way to introduce the methodology gradually in a traditional engineering course. The actual situation of the course was taken into consideration, including its history and the particular type of student that signs up for it, so that the specific actions taken are not immediately applicable to other engineering courses. However, we feel that the methodological principles of this experiment and practical advice based on it may be generalized.

This experiment is part of an ongoing curricular and methodological reform at PUC-Rio's Technical and Scientific Center (CTC), the purpose of which is to train professionals with the necessary characteristics to face the present economic and technological context. In short, such a professional should be:

- a solver of problems with a technological basis who is able to create, design, and manage technological activities;
- self-recyclable: someone who has learned how to learn, who knows how to administer his or her own information flow;
- enterprising: someone who builds his or her own future and has business acumen;
- able to work in a multidisciplinary team, mastering oral, written, and iconic expression;
- able to use technological innovations;
- ethical: knows how to assess the social, economic, and environmental impact of his or her activities.

In order to achieve this, it is necessary to make students active, creative, and participative, establishing links between academic learning and the real world. Students must not only be taught certain contents and trained in the use of certain procedures (say, those of Course ELE1130) but also acquire an attitude that is quite different from that of the typical student who has just concluded the Basic Cycle (nowadays).

Most students have no self-discipline, are inclined to pass the buck, seem to stick to a high-school mentality, see knowledge as compartmentalized, and think that studying is just doing exercises. Consequently, they find it difficult to deal with abstractions and to grasp concepts, although they find it easy enough to calculate: to them, knowledge is a collection of calculating protocols, formulas to be applied without being understood. They have a laid-back attitude: they expect the teacher to reveal to them the right formula that will help them get the desired grades.

At PUC-Rio we always have a reasonable number of students with an assertive personality, who are sure of themselves and are able to face challenges. Most of them come from the Basic Cycle's "special classes" and have never failed a course. For this reason, they follow the recommended curricular periodization. But most students are quite different: they move in groups and adopt group views — a defensive attitude — and have the low self-esteem that is typical of people who have never achieved anything on their own, because they have always relied on outside help. The initial state of the two groups is the same, except for their self-esteem. Confronted with new situations, such as the methodology described below, members of the first group react more quickly and with autonomy, while those of the second group need special care.

It is necessary to change the attitudes of students in the second group, their behavior and their attitude towards knowledge, learning, and work. That is why the Department of Electrical Engineering decided to change drastically the teaching strategy of the course taken by students just emerging from the Basic Cycle: Electric Circuits II. A hands-on strategy along the lines set forth in [1] was chosen, for reasons that will be explained in the next section.

Description of Course and of Strategy Employed

Course ELE1103 — Electric Circuits II, usually taken by fifth-term students, is the gateway to the Department of Electrical Engineering, after a Basic Cycle predominantly concerned with mathematics, physics, and computer science. The immediate prerequisite is ELE1102 — Electric Circuits I, an introduction to typical circuits.

The syllabus of ELE1103 is traditional: a review of the solution of ordinary linear differential equations, the Laplace transform, first- and second-order circuits, steady-state response, impedance and admittance, Bode diagrams, filters, and the use of operational amplifiers and of circuit simulation programs in the laboratory. The textbook used in 1997 was L. P. Huelsman's *Basic Circuit Theory* (Prentice Hall, 1991); in 1998, it will be replaced by R. Dorf and J. Svoboda's *Introduction to Electric Circuits* (Wiley, 1996).

The course consists of 4 hours of theoretical lectures and 3 hours of lab work per week. The average number of students is 45; in the year's first term the students are those following the recommended periodization; in the second term, those who for some reason have fallen behind, usually because they failed some course. The average rate of student failures is from 10 to 15 percent. Failures tend to be more numerous in the second term of the year.

Before 1997, a conventional teaching strategy had been adopted. There were theoretical lectures based on the textbook and practical activities subordinate to the theory, usually organized as a set of previously defined experiments, each exploring one of the concepts studied in the course.

This teaching strategy made it possible to cover the targeted content in the allotted time, but it presented each experiment as no more than an instance of the theory. The natural difficulties (reality resists theoretical knowledge) tended to be seen by students as instrument trouble: the University, they felt, was skimping on quality equipment. Also, though students projected their own circuits and specified components in accordance with what the market had to offer, they felt they were following a rigid protocol, merely testing the theory: just another school assignment.

The courses were criticized for not integrating the concepts being taught into students' own conceptions (i.e., their universe of meanings); this was due to the fact that students did no more than test the effectiveness of an external discourse, instead of constructing internally their own conceptual system. Thus students grasped neither modeling relations (reality $\rightarrow$ physical model $\rightarrow$ mathematical model) nor the effect of the precision level being adopted: the experimental error was seen as equipment failure, for theory supposedly represented reality "truly." Students saw the resistance of the real as something that had to be eliminated by someone else (engineers ought to design better equipment), not as something that must be understood, a limit of the theory, a consequence of reality being more complex than theory allows for. Further, students were unable to place themselves in the shoes of the engineer who "ought to design better equipment."

In short: even though the methodology adopted made it possible to reach the official goal of covering the entire content of the course (i.e., everything specified in the syllabus) and conduct all the right experiments, attaining low failure rates, still the course failed to change students' attitude in the way required by the CTC's curricular reform.

Since the basic problem seemed to be student attitudes, it was decided to change drastically the way students were treated. They were to be seen as future professionals, not as dependent teenagers: they were tired of being treated like children! Schematically, it was decided:

- to think of teaching as a professional activity aiming to train fully rounded professionals to perform in the market and in society; to teach professional formalism; to treat students like adults;
- to encourage students' commitment by setting up the teachers' and instructors' commitment as an example;
- to require a specific attitude from students, adopting a disciplinary code for incoming Electrical Engineering Students, including explicit, previously established rules for students and teachers, with clearly defined limits, rules that are actually enforced.

The usual content of the course was maintained, and it was attempted to interconnect various areas of knowledge by means of a multidisciplinary approach centering on engineering.

Only open-book exams were used, all consisting of questions that attempted to relate the content of the course to real-world problems. Instead of long sets of questions involving only calculations relying on fixed protocols, the new exams contained intelligent problems, not all of them necessarily having been explicitly discussed in class. The theory, it was decided, was rich enough to allow this without posing exaggerated difficulties.

The aims and methodology of the practical lessons and their articulation with the theory were entirely changed. In brief, the new approach was:

- to provide an overview of the Electrical Engineering Course, placing electric circuits within a larger context;
- to pursue a multidisciplinary outlook, one not limited by the boundaries of the discipline;
- to invert the concept-experience relation, forcing students to construct concepts as they conduct lab experiments and feel the need to rely on particular concepts in order to solve a particular problem;
- to propose problems with industrial characteristics, arriving at definite products that are as closely related to the practical application of Electrical Engineering as possible;
- to pursue a view of industrial production and require commercial-quality presentation;
- to avoid predetermined protocols and opt instead for industrial specifications, introducing the notion of project stages and monitoring;
- to demand that assignments be presented in oral and written forms, with Power Point*-type tools, for instance;
- to challenge students by promoting competition between different teams, each one presenting a solution for a proposed problem;
- to have an outside jury evaluate projects and solutions, if possible one that includes industry representatives.

Organization of Practical Lessons: Experiments and Projects

The daily requirements of the Electric Circuits Laboratory are centered on behavior: attitude, discussion, interest, approach to the problem, and techniques used. The weekly requirements are the outline and the report, with the following structure: object, theoretical development, models and circuits, components (with values actually found in stores) and instruments, digital simulation, and bibliography. The reports in addition must include: comparison between results of experiment and results of simulation, justification or refutation of models and circuits, and verification of circuit operating range. Both outline and report must be written in academic or industrial style, in clear, concise, and conceptual language. The report has a documentary purpose and is graded.

At first, students conducted certain classical experiments, working in teams, in order to fix some concepts and bring out the gaps in their knowledge and their personalities. A few experiments were conducted on filters conceived as signal processors. It was observed that students had some difficulty in distinguishing between first- and second-order filters and understanding the concept of time constant. The preconception of electric circuits as instantaneous had not been shaken by the study of theory. Students reacted as if there was no inertia in electric circuits. For this reason, they were required to examine experimentally the consequences of inertia, measuring time constants, filter responses, and energy × signal curves. This is the usual methodology: to find out what students' preconceptions are (in this case, the idea that electric phenomena are instantaneous), to show counterexamples to such preconceptions (ordinary phenomena or experiences seen in a new light, contradicting preconceptions: errors reconsidered as manifestations of the real world), to explain the new, substitute theory.

An experiment with relays was conducted in which a circuit was given and students were required to describe how they functioned and discover their usefulness. In this circuit there was an RC filter to eliminate switching noise. This filter was misidentified by most students as a timer circuit, which cast doubt on how much they had really grasped the concepts introduced so far. It should be mentioned that in an earlier class a car-alarm circuit had been discussed in which there were relays and an RC timer; the circuit in the experiment was an extension of the one previously examined.

Since these were semi-directed experiments, with them it was impossible to determine whether students had correctly assimilated the concepts into their previously held conceptions, or — which amounts to the same — revised them so as to integrate the new concepts and make them operational. The best way to check this is to place students in a new situation where it is necessary to apply the concept in question. For this purpose, students were told to design a project that would involve knowledge of the entire content of the course and depend on a grasp of the notion of inertia of an electric system. This is the essence of the proposed methodology: to lead students to solve experimental problems that require application of the new concepts, but in such a way as to go beyond mere description or verification, placing the concepts in a context that is meaningful to students.

Some of the advantages of the method of student-designed projects are evident:

- It encourages an enterprising spirit, for students have to find their own solutions.
- It stimulates creativity in problem-solving.
- It encourages the solution of conflicts through investigation: students search information impelled by necessity.
- It teaches students to divide a problem in stages, devising their own way to solve it.
- It promotes the integration of students into the industry, since they must specify, buy, and use commercially available components.
- It requires that deductive teaching — from the general to the particular, from learned theory to verified experiment — be replaced by inductive teaching — from the particular to the general, the specific case being verified and leading to the general theory.
- It allows result-based evaluation of projects, which is simple and objective.
- It makes it possible to underscore individual abilities and limitations, giving them the necessary treatment, since each project is carried out by a team.

The major objection to the method is the time it takes for students to reach their own solutions. The project method is much more time-consuming than one that relies on induced experiments. In other words, given a specific period of time, less content is covered when the project method is adopted than in a conventional course. On the other hand, a different kind of learning process takes place. For a discussion of the differences between the views of knowledge and learning involved in this issue, see [1].

Since the course in question had a previously specified content, it was decided to use a mixed strategy, combined with careful selection of the problem proposed according to the following criteria: possibility of being solved in two months' time, evident industrial relevance (relatedness to real world), use of concepts specified above, coverage of content of course, and relatedness to other disciplines (multidisciplinarity).

The chosen project was a high-tension switching system (127V, 9A) — a no-break - a battery followed by a dc/ac converter such that, whenever the main source happened to fail, return the equipment automatically to the main source once the energy supply was normalized. It was suggested that the protected equipment be a personal computer using the Windows* system. This was a problem actually experienced by students at the time, when the frequent blackouts were the regular excuse given by those who failed to hand in their assignments on time.

It was explained to the class that the that long transmition lines behave like a; that charges behave like inductors and resistances; that the system may be represented approximately like a second-order circuit, generating overshoots in the return of the current. Hence the need for a timer to delay the return to the main source. The use of RC circuits as timers was discussed, as it had been earlier in connection with the car alarm. The use of relays and of a contactor (a relay with several high-power contacts) was radically different from the experiment previously conducted with relays in which a filter was used to suppress switching noise. On the other hand, the relay in this case is an automatic actuator, which allowed the introduction of the elementary concepts of the area of controls and servomechanisms. Coverage of the different topics of the course is given in the table below, which includes an evaluation of the results obtained.

Stages	Concepts	Necessary background	Results
project	Ohm’s law, Kirchoff’s rules	prerequisite course (Electric Circuits I)	quite good
switching	second-order circuits	electric systems, second-order responses, modeling	quite good
timer	first-order circuits	numerical simulation, power factor, time constant	very good
use of manuals and booklets	—	reports and outlines	excellent
final presentation of assignment	—	conduct, ability to make oral presentations	excellent

Table 1: .Different topics covered by the course including an evaluation of the results

Early attempts at a solution used relays built in the lab, which proved inaccurate and slow. It was felt to be necessary to use industrially-produced relays, Siemens being the selected manufacturer by the students themselves after consults to equipment catalogs. The company was contacted by the students and was willing to participate, financing part of the equipment and giving students access to company facilities for construction of the prototypes. It is important to say that other companies (Conecxel e Cuttler&Hummer) financed also some projects, after contacts made by the students in a industrial congress in São Paulo.

A rather complex evaluation method was adopted, the idea being to make students feel they were being evaluated throughout the course and not just at the end of the term. The evaluation was divided in three components: the first continuously measured the behavior of each student, the second the student’s effort, the third the student’s project and the prototype of the equipment designed. The third component is the most important, for it is essentially objective, in that it does not rely on the teacher’s opinion. Once the problem was solved and a functional prototype was built, teams were evaluated taking into consideration the following factors: the production process (spelled out in a document), the diagram of prototype production, the budget spreadsheet, criteria of design, prototype performance, suggestions for large-scale production, prototype presentation, documentation, and final presentation. It was decided that at the end the projects would be presented to a jury made up of teachers and practicing engineers, and that each team would simulate a company trying to sell its equipment. All teams had to use a presentation program, as Power Point*, and to adopt a professional conduct.

The organization of students in teams is made necessary by the very complexity of the project and by the general goals of the discipline. Teams were randomly formed (in an actual company one cannot choose one’s coworkers), and each team nominated a manager who was required to perform as such. Within teams, each student tended to take on the function that appealed to him or her the most, in conformity with his or her background, interests, and abilities. Hence the importance of emphasizing in the evaluation the individual's behavior in relation to the problem, so as to avoid passing a specialist in final presentations who knows nothing about the circuit in question. Working with teams requires special classroom dynamics, a subject to be dealt with in the next section.

Attitudes of Teachers and Instructors: The Classroom as Stage

If the proposed system is to function properly, the teacher and his or her assistants must adopt the appropriate behavior, which may be summed up in a few precepts, listed and discussed below.

- The teaching team must act with professional formalism and demand a professional conduct from students. No paternalistic attitude should be indulged in.
- A team spirit should be encouraged between students and teachers.
- The teacher should act not as one who explains or repeats established knowledge, but rather as one who guides students as they build their own knowledge, someone who questions, who asks questions but does not supply the answers. The teacher may suggest ways and must criticize results and methods (by pointing out counterexamples and flaws, for instance), but he or she may never present an algorithm or protocol that can be mechanically applied to solve the problem. The teacher's job is to show students how to catch a fish, not to catch fish for them.
- The teacher should consider students' positions and take them from where they are to as close as possible to the desired goal, and not just check whether or not they have reached the goal. The teacher must take into consideration the fact that some students are slower than others, that individual students react differently to different teaching strategies, and that it may be necessary to provide assistance and extra time to those who are experiencing difficulties.

Thus the teaching team began by gratifying students' egos, reminding them that they had all been able to enter the department of their choice, which was one of the most exacting departments in a major university, and so forth. Next, they presented material in the conventional way. But after a while the teacher began to question behaviors and results, saying, "Well, I don't know. What do you think?" The teacher was no longer the person who monopolized knowledge; he or she tested and questioned, expressed doubt, made it possible for students to ask naïve or trivial questions. It became possible to make mistakes and for mistakes to be examined with no embarrassment. Thus the basis of any learning process was achieved: the possibility of making mistakes and correcting them. The methodology used allows tentative projects, experiments, checking for mistakes, correcting them, none of this affecting the final grade. The grade is decided on when the final results come in (as described in the previous section), so that students are freed from the fear of getting a bad grade because they made mistakes in the first exam. Clearly, it is necessary to constantly emphasize that time is running out, so students will not put off everything until the last moment.

The projects were carried out at the Circuits Laboratory of PUC-Rio's Electrical Engineering Department and nearby labs. All of the labs were kept open from 7:00 A.M. to 11:00 P.M. whenever necessary, under the supervision of the lab technicians and a number of teachers. In some cases it was necessary to request assistance from other teachers, due to the large number of teams working simultaneously. The real limit was set by the tools and equipment available.

Space and time was shared with the freshmen in Introduction to Engineering and students in middle-level courses. In such occasions the Electric Circuits students felt they were setting up an example for the freshmen and actively collaborated with them, in a relationship that was beneficial to both parties.

In the second term of the year, it was necessary to postpone the final theoretical examination and provide additional classes for the poorer and/or less self-confident students, who needed more time to understand the course's proposal and act accordingly. One student who had gotten low grades (below 3 on a 0-to-10 scale) in her first three exams exclaimed, in the session before the fourth exam: "Oh, is *that* what you want?" and from then on scored above 9! Up to that point she had been trying to repeat problems that had already been solved instead of trying to reach a real understanding of the issues involved. It took her two months to realize that the exams always involved new problems, even though this had been repeatedly stated in class.

Student Presentations and Results Achieved

The final evaluation was based on a presentation of the prototypes before a jury made of teachers and engineers, in a trade-fair atmosphere. Students were required to behave like professionals and to use overhead projectors, leaflets, and manuals. Their response was extraordinarily enthusiastic: they caught the spirit of the game and worked intensely, stimulated by the competitiveness and the sheer novelty of the experience. They sought teachers at all hours to ask for help with details about their projects or presentations. In both terms of the year, students experienced the final presentation as a grand game, conjuring up fictional companies that supposedly manufactured the equipment, complete with trade names, ads, and so on. In their presentations of projects they wholeheartedly adopted a “market” perspective: they showed up dressed to kill and very much motivated to put their best foot forward. Each team adopted a different approach, which reflected individual qualities and the synergy of these qualities in the team. In some of the projects the prototypes were up to professional standards, even though this was the first course in the Department that they were taking.

The final results were considered excellent by teachers and students, although criteria for passing were stricter: 21 percent of the students failed in the first term, 17 percent in the second. At the end, the winning teams repeated their presentations at a university ceremony, and other teachers and members of other Departments were enthusiastic. The desired change in attitude was achieved, as the final presentation made clear. Study was no longer seen as drudgery: instead, it was a challenge to be faced with gusto and vigor, and with the certainty that what was being learned would be useful in the future.

The success of the methodology will be truly verified when the later courses are monitored. Though a more objective evaluation has been scheduled for the future (the Control and Servomechanisms II course, in 1998), the teachers in charge of the courses immediately following Electric Circuits II were asked about the behavior of their students. The teachers replied that it had changed: students were more serious-minded and demanding, and seemed unusually adroit at relating theoretical models to practical situations, proposing suggestions that indicated a deeper insight into the subjects in question. And, of course, they finally understood what electric inertia was all about!

The highly positive results achieved led the Electrical Engineering Department to officially adopt the new methodology for the Electric Circuits II course, and to extend it gradually to other courses.

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