Electrical Measurements: An Integrative Course Unit

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Abstract - *This paper is about a new experience on teaching and learning where an existing discipline was reshaped using elements of the Learning Outcomes (LO) pedagogical approach. Its original character made it suitable for playing the role of an integrative course unit. Learning Outcomes of different nature were brought together to determine its new role. In this context the method of assessment that has been implemented is presented. Finally, it is examined the teaching strategies envisaged as the way of providing the students with the means to demonstrate the LO's.*

Introduction

Discussions aiming at improving the engineering courses have been involving a number of educational experts, teachers, students and even employers and government agencies. The facts, which triggered such interest, are broad and diverse. Governments want to increase the country's productivity and spend fewer resources to educate more people. Employers, on the other hand, are interested to find better ways to increase industry strength and overtake the foreign competitors. Teachers have to respond to these pressures designing courses in tune with the new trends. The students are looking for new competencies, which place them in a better position not only in the labour market but also as citizens.

Brazil being not an exception to the rule is also undergoing an extensive transformation in its educational systems. At the Federal University of Minas Gerais several new experiments concerning to electrical engineer education have been conducted since the early 90's. These experiments have converged recently to a large curriculum rethink, which is the theme of a companion paper [1].

This paper deals with one of such experiments, involving a discipline of the undergraduate course, namely Electrical Measurements (EM), which is concerned with electric and electronic instrumentation. The unit is offered at a middle level to students starting their third year. It comes just after the basic courses (Physics and Maths), and represents one of the first contacts the students have with subject specific disciplines (along with two other courses, in Electromagnetic Theory and Electric Circuits). At intermediate level, the Electric Engineering Curriculum has to accomplish two goals which can be summarised as follow:

- present an introduction to general engineering methods related to system science, such as up-down and down-up design and modular design;
- present specific subject contents including basic Electric Engineering theories and technological practices;

The importance of these goals is twofold. One is for motivational (pedagogical) reasons and other is to help the student to develop his/her design skills [2,3,4]. These points will be emphasised here, with additional arguments of some other nature.

Other two disciplines offered at the same level, namely Electric Circuits and Electromagnetic Theory are constricted to work with fundamental theories and their respective analysis methodology. Therefore they are not the suitable vehicles to the first objective mentioned above.

Until some years ago EM, the discipline in focus, had only the limited objective of presenting technological facts. The way the most important electrical measurement instruments work were explained in detail. Thus, the students were trained in their usage and in the analysis of the collected data. The related standards were also presented.

Since the early nineties a rather different approach has been introduced. A set of learning outcomes were described and if the student is to succeed in the course he/she has to give evidence that he/she is able to demonstrate them. This is carried out in an environment where it is emphasised the strong "knowledge integration" existing in the scientific methodology. Instead of being only a collection of facts, EM has now a more formative role. Therefore, it serves to multiple purpose, which are after all related to the previously presented objectives:

- integrate basic knowledge recently acquired on Physics, Maths, Statistics and Computer Science, in an Electrical Engineering framework where the students have the opportunity to develop their problem solving skills;

- co-present parts of the circuit theory, concurrently learned in another (Electric Circuits) discipline, yet in an application (or simulated application) framework;
- get in touch with some subject specific topics that will be dealt in more detail in advanced level disciplines, such as electronic devices usage in electronic circuits synthesis, signal processing fundamentals for signal conditioning, the hardware-software interaction in data acquisition systems, and so on;
- develop behavioural attitudes toward collaborative team work;
- develop some basic communication skills, in a systematic oriented approach.

The learning environment was planned to emulate the work of scientists or engineers (working in technological development). It has consolidated knowledge coexisting with others that are not well grasped, being at that stage only viewed by the students as primitive concepts (black boxes). This approach is rather different from the classical academically formatted knowledge model, which follows the artificial structure of "brick over brick". Where the knowledge building is presented only in its already well-structured faces, with an available and well-known net of logical connections that lead the student from the point where he/she has some "basic knowledge" to become an expert who masters "the specialised knowledge". This model aims at developing the student competencies usually presenting the knowledge in a static manner and not as a product of a lengthy maturation, which has gradually attained a compact and well-established form. Nothing is said about theories that at their earlier stages had several weakness, misconceptions and were poorly structured.

Knowledge conceived as "the nature of things", and taken as something previously given, that the learner is supposed to apply is nowadays not suitable for a competitive engineering practice. What counts is that sort of knowledge viewed as an evolving body. The one which one part works inside the other, with interactions and dependencies among them. Where it is possible, at any time, a complete revision of the problem boundaries and even of its description − this is the kind of knowledge of the highest quality, since it generates more knowledge.

Extensive modifications are being proposed in the scope of a new curriculum [1]. It became clear that some of the changes should be tested before being fully implemented. The discipline under discussion here had attributes, which made it perfectly adequate for that experience. One is the lack of fundamental subject specific contents and the other is its technological nature as defined in the context of the present curriculum.

Thus, the discipline was redesigned as an integrated course unit. The fundamentally new set of competencies that the students are supposed to demonstrate at the end of the new EM course is even related with their approach when facing science or engineering problems. One question which is posed to students, as a recurrent theme during the term:

> *Considering an user-specified need such as getting information on some physical process, how to define the problem in a design-relevant format, and how to build a system, possibly composed of several interconnected sub-systems, which is able to execute the desired functions?*

Learning Outcomes

This section presents and discusses the Learning Outcomes [5] that have been devised for the course unit. This was done having in mind the conceptual model that has been presented in a previous section and also, the role of an integrative unit of a particular level on the curriculum model.

An outline syllabus of "Electrical-Measurement" has been stated many years ago as:

> *Circuits. Fundamental notions on instruments and methods employed in current, voltage, resistance, inductance, power, power factor, and frequency measurements. Magnetic measurements and introduction to non-electric quantities with electric methods. Electric and electronic devices.*

This description had been carried-out as early as 1977, within a large curriculum reformulation occurred that year[1]. The focus on subject specific contents is evident. Since that time, the electrical engineering curriculum at UFMG has undergone a number of minor revisions, either to update subject specific contents or to solve structural problems that naturally arise with time[2]. The official EM outline-syllabus has been left unchanged, although another discipline has been introduced to a higher level in order to take account of additional topics concerned with electrical instrumentation.

The changes that came up when designing the new (EM) course unit were outlined in the last section. In there it was pointed out that the subject specific contents stated in the syllabus has become almost a "pretext" to engage students in a learning process with a much more deep formative purpose. The subjects specific Learning Outcomes are now associated to others of different nature. Therefore, the behavioural attitudes, problem solving and communication skills were added and the discipline now is characterised by that larger set of learning outcomes associated with a proper assessment method and an adequate teaching strategy.

The set of Learning Outcomes (LO) was written after a lengthy course of actions. First some aspects concerned to their description were established. A proper syntax (verb-object-complement) was observed. The verbs at the beginning of the phrase were derived from a list devised for purpose. A large number of LO's where then described encompassing subject specific as well as general competencies (knowledge, skills and attitudes). This was proved to make assessment easier and more consistent. The objects and complements are the result of a process where contributions from other lecturers as well as of non-academic engineers were taken into consideration.

The document of the course unit encompass the LO's, (together with the assessment method and teaching/learning strategy) is written below. Therefore, if the student is to succeed he/she shall demonstrate that is able to:

1. describe the main functional blocks that compose a measurement system;
2. employ[3] the main (traditional or state of the art) instruments used to measure voltage and current signals and their associated quantities, such as power, energy, frequency, time and impedance;
3. determine the validity and the reliability of measures taken from a given system attached to a signals source;
4. define and select appropriate strategies to solve problems using electrical measurements as the subject;
5. communicate the results of technical works in a clear and coherent way, with the generation of systematic and meaningful documentation for any designed and assembled system.

The problem solving strategies which, according to the "system theory", make coherent the new learning scheme outlined in the last section are described below:

- the modular design of systems, with design specification in terms of a functional description of each module;
- the associated modular testing of systems, employing functional descriptions;
- the up-down design, starting from loosely specified user needs, going through a series of increasingly specified functional blocks and reaching a fully functional system (at prototype level);
- the down-up design, starting from several previously built general purpose blocks that execute some specific functions, taking them in order to build complex systems that execute some specific function;
- the concepts of black, white and grey boxes, as descriptions of subsystems which can be interconnected, and that may lead to complex systems with specifiable behaviour.

Assessment Method

In traditional courses the focus is on course contents where the teacher plays a central role deciding previously the course options for the student. The lecture (process)is one of the key elements. By contrast, taking the Learning Outcomes approach the student is responsible for his/her educational process and the course is centred on the demonstration of the LO's.

The method of assessment was designed having in mind that it is more important to have new attitudes towards this key element of a course unit, than to find out new forms of assessment. The method of assessment is understood as the procedures the teacher may use to make sure the LO's were really demonstrated by the student. It also determines how elaborate an outcome shall be demonstrated [7]. It comprises a number of components, which are the elements used to assess the outcomes. The components can be split in two large groups [9]: In the first are those where the evidence that the student have demonstrated the LO is given by writing or analysing written texts. In this group are those components well know in engineering courses such as written tests, reports, assignments and theses, among others. In the second group are those components which are less dependent on written pieces and they include orals, games, projects, posters, computer programs, etc.

The assessment method used in EM is still being precisely tuned. Due to the new character of the discipline, the role played by close written tests has been steadily diminished in favour of a problem-working activity, where the students have to design and build a measuring system according to a broad (general) specification. The formative aspect of the assessment is emphasised. At the moment, the evidence that the students can demonstrate the outcomes is still given by written tests and the project itself, which comprises the assemble of a measuring system, an oral examination and a report. Summarising, the method of assessment for the group of LO's has the following criteria:

L.O. 1, 2 and 4: Written test with short and objective questions. An example of such question can be: *Draw a block diagram of the analogue oscilloscope, and explain the role of each block such that the overall set works*. And another can be: *Suppose a computer with A/D card. Write the algorithm for a single-phase active power meter, considering instantaneous current measurement in port 1 and instantaneous voltage measurement in port 2.*)

L.O. 2, 3 and 4: Written tests, possibly with numerical calculations, where some precondition is given, asking the student to find the solution. A possible question can be: *Determine the maximal expected error in the measurement system, presented in the diagram bellow*. (A diagram with several blocks and their characteristics is presented)

L.O. 4 and 5: A project involving the designing and the assembly of (fairly) complex measurement systems, in view of the students' background. The task is considered complete after the demonstration that the system works by checking each one of the given specifications.

L.O. 6: A word-processed report about the project. The presence of topics such as introduction, methodology, results and analysis, conclusion and references is checked. A proper technical writing style is suggested. Block diagrams in at least two hierarchical levels (a functional and a component level diagram). Information about what voltage sources to employ, where to plug the signal inputs, and also the procedures used to find measurements errors among others shall be included in one of the topics (e.g. methodology, appendix).

Behavioural attitudes, such as "work collaboratively", proved hard to assess. Nevertheless, the students are constantly told that they are being assessed in these terms too. Some of those who fail in participating fully in the team project are easily spotted. However, it's not so easy to distinguish those who took the burden favouring the team and those who did not.

Teaching Strategies

The proposed new (Electrical Measurement) course unit involves a substantial load of teaching strategies that should be implemented. A brief description of these strategies is presented in this section.

The discipline lasts for one-semester. Forty five hours are spent on lectures and thirty hours of practical work. In addition to this classroom time, the students, split in small groups, are encouraged to book meetings with the teacher to discuss either the progress of their project or any other topic concerned related to the LO's. The first case is mandatory and the former occurs by students' initiative. Recently an Internet discussion list, where teachers and the students alike must subscribe, was conceived and put in practice.

Laboratory

The laboratory [10] has a fundamental role here, where the students have the opportunity to work in a problem solving basis. The equipment available to the students comprises five sets of:

- one oscilloscope (analogue or digital);
- one proto-board;
- two Multimeters;
- "virtual instrument"(a data acquisition card and a special program to drive it configuring a measurement instrument controlled by a computer);
- one electrician tool kit .

Other instruments such as LCR bridge, counters, resistance boxes are also available but in a unit basis only. This laboratory belongs to a group of laboratories that are managed on the basis of "open laboratory"' since 1993. This implies that it is opened all day long, and the students may develop the assigned tasks at a time of their convenience. The nature of the tasks is also directed mainly for the synthesis of engineering systems, instead of the classical emphasis on the "demonstration of a phenomena" or on "learn how something works". Several pedagogical advantages and instructional issues also appear explained in greater detail in the report of a very similar scheme that has been applied in the Arizona State University [11], in 1996. In a curious coincidence, the name of such experience in that American university has also been named "open laboratory"', as in UFMG.

In each lab section the students work to solve problems proposed by the teacher. In the first few the teacher plays a more important role but soon the students are encouraged to act more independently. Nevertheless, the problems devised are such that tips are always given and the teacher is always about in order to motivate the more timid students. This is considered an important approach, considering the student development stage.

In these lab sections, the problems assigned to the students are such that they involve the designing, assembling and testing of some fairly complex measurement systems. The problems are conceived in order to involve the use of instruments and the application of measurement techniques to obtain the values of voltages, currents, electric power (power factor and energy), impedance and frequency (time). The students are encouraged to use the virtual instrument to observe and measure the electric signals and eventually output them to a word-processor in order to produce a short report.

The experimental project assigned to each group of (up to four) students at the beginning of the semester involve the task of building a DC-value current-meter. The operation range is specified in terms of measured values, frequency range and frequency rejection shape, input impedance, linearity and maximum errors, and output device. They also have to write a computer program in C-language, which will drive the A/D card plugged to a PC. As the A/D card has many analogue inputs, they have to use at least two, in order to show the voltage (current) signal at intermediary points and at the output. The characteristic of the "virtual instrument" is also specified. The main purpose of the project is that it constitutes a framework where the student may develop his/her competencies to solve problem, work on a team basis and to improve the written communication skills.

Lectures

Traditionally, the lecture is the most important teaching activity in engineering courses. Even in cases where the course has a more applied oriented approach. EM was no exception to this rule.

Despite the fact that the number of hours assigned to the discipline has not yet changed an innovative attempt to present a unified and scientifically based view of the subject has been done. The purpose here is again to give to the students the necessary conditions for them to demonstrate some of the Learning Outcomes asserted for the discipline. Below it is summarised the main points involved in these changes.

The lecture must regain its original purpose [12] in which the student will be presented in every class with a broad idea about the topic (or topics) concerned such as it may guide the students' learning. The immediate consequence is that number of necessary class in many cases can be dramatically reduced.

In more specific terms when delivering the lecture, a signal is understood as a mathematical function of the time. This function may therefore be described in terms of a Fourier series (or integral). Each mathematical operation may be performed by some functional blocks: integration, mean value extraction, variance extraction, multiplication, time counting, events counting, and so on. The physical realisation of each block may be done by several means, including electromechanical devices, electronic analogue devices, electronic digital discrete devices, and by a general-purpose digital processor. Each physical implementation leads to associated advantages and limitations, which the students are encouraged to find.

The selection of a set of building blocks (with their respective functional descriptions) and their integration in the design of a complete working device is the core of the measurement system design. So the lectures start from basic physical concepts, showing the path through mathematical representations of the signal, the system to be measured, the measurement building blocks and the several noise sources, until the conceptual design of a measurement system. The student is encouraged to think in terms of objects with specific functional behaviour, which in turn may be joined in order to build other objects, of higher level, yet of the same nature.

Therefore in the lectures the students are provided with a universe of familiar objects, with relations among them intended to shape their thought in face of a measurement problem.

Internet

The Internet is proving to be a very convenient tool for complementing the traditional lecture scheme in the Electrical Engineering program. Other courses besides EM also employ the same scheme described here.

The Internet important tool for usage in the EM course is the mailing list. The teacher and all the enrolled students are included in a mailing list to which any of them may send messages. The messages are sent to all the list subscribers. (Sometimes students that are not enrolled in the course are inscribed in the mailing list and take part in the discussions, what is encouraged). The main advantage that has been shown, up to now, is the fast communication, at any time, with a big group of individuals. In this way, questions that otherwise should wait one week to be answered can be answered in no more than one day. The discussions are also available to all students, so everyone takes advantage of all questions that emerge.

Another important usage of Internet has been for its sources of technical material. The complementary references of EM includes, at this time, the mentions to some sites in which application notes on devices usage are available. This has been an interesting experience because the students normally assess the sites during moments of relaxation and see this task not as a burden but as fun.

Conclusion

In this paper it was described the experience of reshaping a discipline originally designed in the context of an aged curriculum in order to achieve an integrative role. A new educational approach based on the demonstration of the outcomes was employed. The objectives were asserted at first and them the Learning Outcomes were described. Assessment methods designed to check the student competence in terms of the LO's were proposed. At the same time new teaching strategies were conceived.

Despite this experience has been limited to one course unit, it clearly demonstrated its viability to be extended to the whole curriculum. The positive aspects are twofold. First in terms of the importance of its integrative role grouping subjects of distinct nature and demonstrate a way of integrate them in a predominant subject specific discipline. Also, it has showed the advantages of describing the learning outcomes bringing them with an associated assessment method to perform a central role in the learning process.

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[11] That curriculum reformulation has followed, in its general philosophy (adapted to the Brazilian conditions), the ideas expressed in [6], published in 1967, which has also given the directives, in broad sense, for the engineering education reformulation in American schools occurred in the late 60's and earlier 70's.

[2] The time factor here is caused both by the peace-meal approach used to carry out curriculum revisions, by the educational approach based on subject specific contents and by the fragmentary course structure. As the curriculum mangers tries to update the disciplines the problems come-up, make mandatory the revisions.

[3] The Learning Outcomes described in this work were stated supposing the verbs following a hierarchy classification [8]. That is, if the student has demonstrated that he/she is able to employ an instrument, he/she certainly can describe it.