

2006-565: LABORATORY FROM THE FIRST DAY: AN EFFICIENT METHOD TO CONVEY ELECTRICAL CONCEPTS TO ENGINEERING STUDENTS

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Laboratory from the First Day: an Efficient Method to Convey Electrical Concepts to Engineering Students

Abstract

In a traditional engineering course, laboratory exercises are presented to students as a validation and reinforcement of the theory covered in the classroom. This paper proposes a change in this paradigm, engaging students first with experiments and then challenging them to explain the results. Subsequent class discussion of the underlying theory helps students complete the analysis of the measurements taken. This approach is being used in a general engineering curriculum to cover outcomes included in the Fundamentals of Engineering (FE) exam.

Two examples are presented to illustrate this educational approach. The first experiment uses the dissectible motor kit sold by Hampden Engineering. Students first examine the different parts of a direct current electric motor, assemble and run the motor, and then take measurements. The second example uses LabVIEW graphical programming tools to build a virtual lab which can help students understand binary numbers and arithmetic and other digital logic concepts.

The approach has several advantages. The first is being able to engage the students. Incorporating algebra-based laboratory exercises in the freshman year helps to motivate the students with hands-on experiences. Also, the students gain a higher sense of accomplishment when they are first faced with a problem that they cannot solve, and then later are able to understand the concepts needed to analyze the problems. Lastly, the students are challenged, keeping their interest and promoting excitement for the course.

Background

The new general engineering program at East Carolina University requires interdisciplinary integration of electrical, mechanical, and systems topics. This integration demands creative pedagogy to ensure coverage of necessary content within limited time. With a brief introduction of the features of the newly-built program, this paper describes methodology required by the curriculum structure. It then presents an efficient method to deliver electrical engineering subjects with two examples. Preliminary results of this initial work are further discussed.

Motivation

Benjamin Franklin's famous saying — *Tell me and I forget. Teach me and I remember. Involve me and I learn* — suggests ways educators should deliver knowledge to their students. This is particularly true for the new general engineering program under development at East Carolina University [1]. The NCEES (National Council of Examiners for Engineering and Surveying) has clearly defined content areas that general engineering students must master in the “electricity and magnetism” area [2]: the

morning session of the FE (Fundamentals of Engineering) exam covers basic concepts including charge, direct and alternating current circuit analysis, and complex algebra; the afternoon session further requires electric machines (motors and generators), electrical instrumentation, and measurement systems, which in turn requires some coverage of operational amplifiers and digital logic. It is quite challenging to teach such a broad range of subjects in one course, although most of these topics are required at only a relatively basic level. An efficient method is required to expose the students to fundamental engineering topics and to get them familiar with the highly integrated educational environment.

Methods

Fortunately, most of today's students have been exposed to various electrical/electronic equipment and have gained some knowledge from their past experience. For example, most students demonstrate fairly good knowledge of personal computers. Many of them have worked on cars and are aware of concepts such as voltage and current. Therefore, possibilities exist for educators to take advantage of the students' background to quicken the student learning process. Furthermore, many manufacturers provide commercial teaching tools that were not available before. These straightforward tools make it easier to teach abstract concepts. These two primary factors permit us to try different ways to use time more efficiently and increase student engagement. In this case, we have students start with laboratories prior to complete coverage of all the theoretical background and encourage them to find answers from later lectures by first exposing them to problems associated with experimental results.

The hypothesis behind this approach is two-fold: 1) Students, after getting straightforward, easy-to-understand, visible results from carefully designed laboratory sessions, will be motivated to learn more; 2) they will become more focused in the follow-on lectures because they come to the classroom with questions from previous lab sessions.

Example 1. Direct Current Motors

The first laboratory is designed with the objectives listed below. In a mechanical lab earlier in the semester, students learned to calculate energy conversion efficiency of motors and power trains. In this DC motor lab, they obtain the input power by measuring the motor current and voltage and output power by measuring the driven prony brake speed and the torque. In addition to reinforcing energy conversion concepts, this lab is intended to introduce the structure and construction of direction current (DC) motors. Also, this lab is an excellent opportunity to teach students general rules for safe laboratory procedures. Before the lab session, the students have been introduced to fundamentals of magnetism and magnetic forces (attractive/repulsive). A brief explanation of the principles of electric motors is sufficient to help them understand at a high level the functions of different parts in a motor.

Objectives:

1. Understand general electrical experiment procedures and safety rules.
2. Identify principal parts of a DC motor.
3. Assemble a Hampden dissectible DC motor.
4. Measure armature and field resistances of series and shunt DC motors.

The lab session uses HAMPDEN MODEL HDI-100 dissectible motors from Hampton® Engineering Corporation [3]. Each station is equipped with DC/AC ammeters, voltmeters, and wattmeters and provides a workbench on which a motor installation base and a prony brake are mounted. With included parts, four types of motors can be easily assembled and disassembled: DC motor, single-phase motor, two-pole 3Φ motor, and four-pole 3Φ motor. The benefits to use this tool are obvious: being able to build a motor that really works greatly fosters a sense of achievement and encourages the student interest to explore more about it; the small amount time required to assemble a motor saves most of the time for students to focus on measurements and therefore improves experiment outcomes; the easy assemble/disassemble processes make it possible to compare the performance of two or more types of motors during the same session, which helps students distinguish the difference between various motors. Furthermore, these motors are based on production quality Baldor motors; thus what students see in the lab is recognizable in a manufacturing or production environment.

With safety rules emphasized first, the students are guided through the Hampden motor station and the parts to be used. During this introduction, they are asked to observe the physical arrangement of the stator, rotor, commutator, brush, and windings of series and shunt fields. Then students, working in groups of four, assemble their motors following the lab manual. After each group builds their DC motor, they measure the resistance of the field windings for the series and shunt configurations. They record all the measurements and are reminded to note the different resistances of the two types of fields. At the end of the lab, the students are given a list of questions based on the lab experiment measurements. They are not expected to answer the questions at this point because they have not yet been exposed to the theory. Topics that will be covered in the following lecture are also announced.

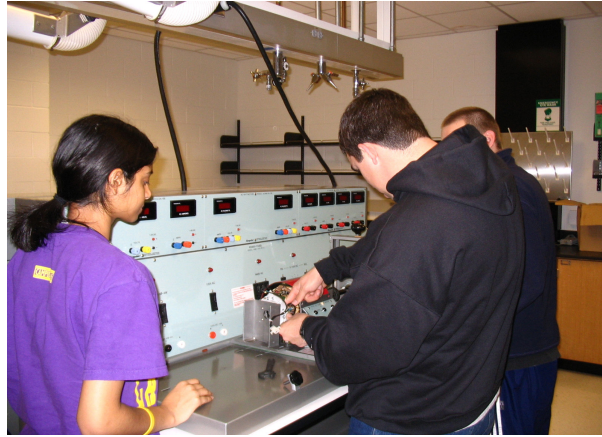


Figure 1. Students build a DC motor using Hampden dissectible modules.

The lecture following the laboratory then teaches the principles, configuration, and physical structure of DC motors. Since the students are already aware of the topics in the lab session, they are focused during the lecture session. The follow-on lecture explains the functions of commutators and brushes, and different configurations of excitations (see Figure 2). Furthermore, the different physical arrangement of the series and shunt field windings that were observed in the lab are covered. The difference of the field winding resistances collected from the previous lab and the reasons for this significant difference are reviewed and explained. The series field winding is connected in series with the armature and must be able to carry large load currents. Therefore, its resistance must be low, which explains why it is wound with few turns of heavy wire. In contrast, the shunt field is in parallel with the armature, and the winding is wound with many turns of fine wire to maintain a large resistance to limit the field current.

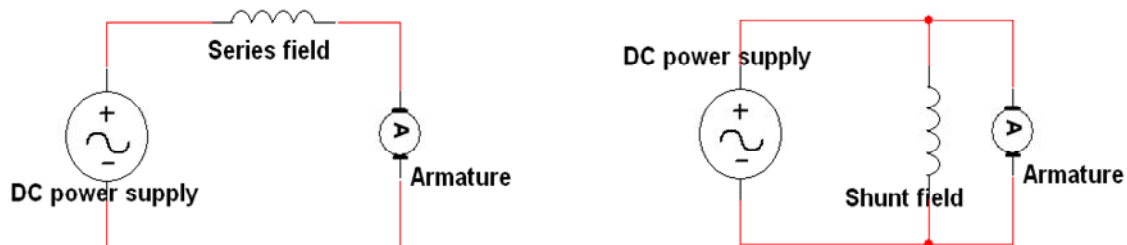


Figure 2. DC motors with series and shunt fields.

Example 2. Virtual digital logic lab

Digital electronics play an important role in today's industrial plants. It is essential to equip general engineering graduates with basic knowledge about Boolean algebra, digital logic, and digital circuits so that they can be ready to explore more if their future career requires them to do so. Traditional digital circuit laboratories in electrical engineering work well to help students understand this subject. However, since this is a general engineering program, a more compact lecture/laboratory plan is needed to teach all these topics within a relatively shorter time than for a regular electrical engineering program.

LabVIEW from National Instruments [4], a graphical programming software package, serves as an excellent teaching assistance to deliver these concepts. The authors develop a virtual lab session that uses LabVIEW to teach basic Boolean algebra and digital logic. Instead of explaining rules of Boolean algebra in a regular lecture, the students are told to manipulate the switches on graphical interfaces and watch the changes of the indicators. With this straightforward observation, they are then taught Boolean algebra rules and truth tables, and then they are required to implement digital logic functions with LabVIEW's graphical function modules.

Objectives:

1. Learn basic rules of Boolean algebra.
2. Realize digital logic functions from truth tables.
3. Understand De Morgan's Theorem.
4. Design simple digital logic.

Figure 3 depicts a LabVIEW interface that is used in this lab session. The students first click on switches on the interface and examine the change of the indicator to find out the logical relationships between input (switches A, B, C, and D) and output (indicators for "A and B" and "C or D"). Figure 4 is the two LabVIEW diagrams to implement AND/OR operations.

Other logic gates, including NAND, NOR, XOR, etc. are also implemented in a similar way. Truth tables are further introduced based on these experiments under the LabVIEW environment and integrated with the above in a single laboratory session. By trying out these virtual experiments, the students examine all the logic rules without excessive explanation. They then are requested to design digital logic functions described by truth tables and to implement them with graphical function modules in LabVIEW diagrams.

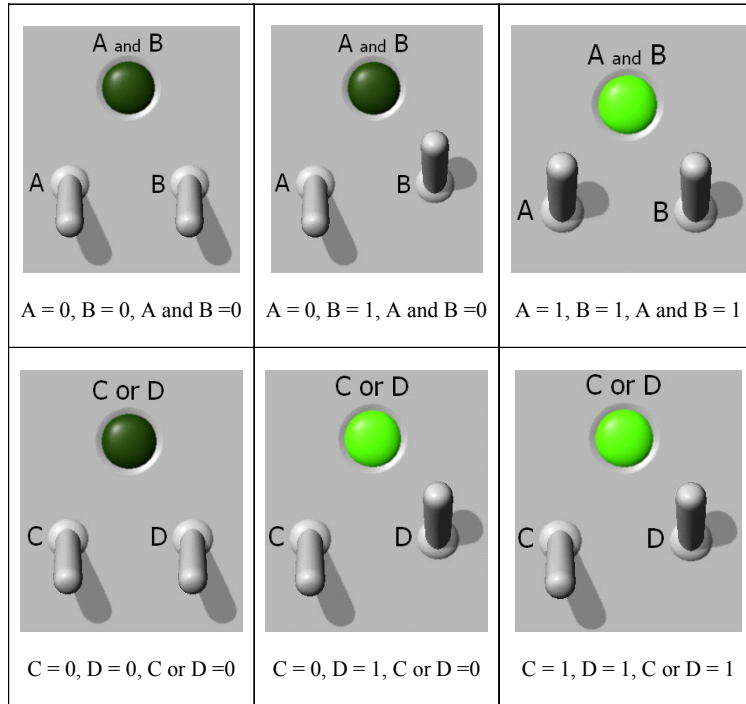


Figure 3. An example using LabVIEW as a teach assistance for digital logic.

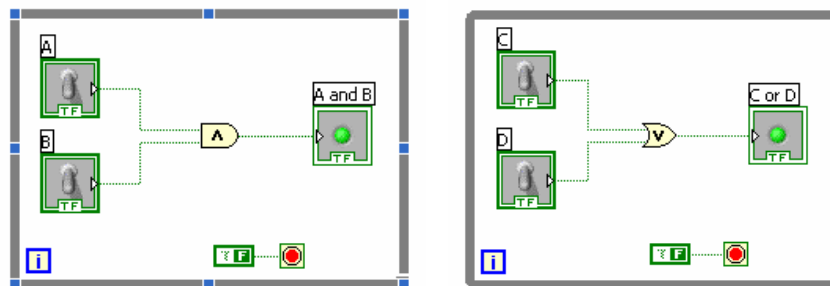


Figure 4. LabVIEW diagrams for displaying digital AND and OR operations.

Results and Discussion

This laboratory-driven learning approach gives students first-hand experience and helps motivate them in their studies while at the same time allows the instructor to cover more material in semester. In a survey conducted at the end of the semester, many students expressed their appreciation of working on electrical equipment closely related to real-world life at the very beginning of their electrical engineering study. Many more agreed that the virtual lab for digital logic substantially helped them understand concepts in digital logic and digital circuits. Particularly, the graphical tools allow visualization of the abstract algebra and allow the students to grasp and retain this basic yet important subject in a short time.

At the same time, this laboratory-prior-to-lecture approach must be practiced with special attention. Several phenomena were noticed and worthy of more examination to prevent avoidable confusion during the lab time. These include:

- Careful investigation is needed to decide which lab to choose for this laboratory-first model. Not every topic is suitable for the model. Some labs require fully coverage of theory before any hands-on laboratory work and related measurements.
- The lab instruction needs to identify clearly those key concepts that need to be demonstrated during the lab session for explanation in subsequent lectures. Carefully designed lab instructions are essential to make sure the students can complete labs in time and focus on the key items.
- Student homework after the experiments is critical. The follow-on lecture is designed assuming that the students have investigated and remembered the measurements made in the lab. Students who are not primed for the lecture may fall behind or get lost in the explanations.
- In the lecture that follows the corresponding laboratory, the instructor needs to review those important concepts demonstrated previously in lab so that the students can recall the lab process and refresh their memory to better associate the lab results with the lecture material.
- Although this approach helps to cover the content in the “electricity and magnetism” area of the FE exam, it cannot cover all of the material. Careful review of the curriculum is needed to ensure that students learn the required and most appropriate material.

Conclusion

This paper presents a strategy to deal with the challenge of covering a wide range of electrical engineering topics under the structure of a general engineering program. A laboratory-first approach is designed to ensure all basics are covered with an extremely tight schedule and to motivate student’s active learning. Two examples were given to illustrate this efficient approach. Preliminary results demonstrate that the method works well when the laboratory/lecture pairs are carefully designed.

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