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A three-step teaching and learning process in an advanced electronics course for non-electrical engineering technology majoring students

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ABSTRACT: The purpose of the *Engineering Technology Electronics* course outlined in this article is to enable the students to apply their knowledge to real world engineering problems. However, it is challenging to teach advanced electronics concepts effectively in a short time to non-electrical engineering technology students. These students lack a deep background in electronic principles and, when taught in a traditional manner, it could lead students to carry out laboratory experiments in a perfunctory manner. Such an approach does not promote a deep understanding of the basic concepts important in the developing engineering technology student skill set. In order to remedy the situation, the authors have developed a pedagogical approach that promotes deeper understanding. The primary objective of this article is to describe the teaching and learning process that the authors have adopted. Preliminary results suggest that this pedagogical approach may enhance students' understanding of advanced electronics concepts. The method comprises a lecture, a computer simulation and a laboratory activity involving physical experimentation.

INTRODUCTION

Electrical and electronics technologies are fundamental enabling tools of modern industry that have been integrated into many fields, such as communications, automotive, security, defence, acoustic systems, consumer electronics, etc. The electronics courses in the Department of Engineering Technology at Texas State University provide students majoring in engineering technology, technology management and sound recording technology with an introduction to the fundamental principles of electronics and electrical circuitry. Engineering technologies are *...instructional programs that prepare individuals to apply basic engineering principles and technical skills in support of engineering and related projects* [1]. These programmes balance classroom theory with practical application in a laboratory environment.

Engineering technology students are expected to be prepared to join the workforce with a good background in practical problem solving. Industry representatives have expressed a preference for engineering technology students who gain both hands-on practical skills and theoretical knowledge, and who are ready to immediately carry out work assignments without significant on-the-job training. Therefore, universities have a mandate from the industry to educate and train students with hands-on experience, as well as theoretical knowledge [2].

In order to familiarise students with electronic devices and circuits, universities must provide sufficient opportunities for students to experience lecture and laboratory experiments, since hands-on laboratory work helps students to understand complex theoretical concepts and apply theoretical knowledge in practice better [3]. However, time and budget limitations make this difficult. Hence, instructors need to design innovative coursework for engineering technology students that will permit effective learning at a comfortable pace.

Generally, electronics courses are designed to be delivered using a two-step process: 1) a lecture is provided to teach the physical phenomena of electronic devices and the theory of circuit analysis; and 2) hands-on practical laboratory assignments are provided, which require students to build circuits and measure their electrical properties. The problem with this approach is that students do not have a good grasp of basic principles before needing to conduct laboratory work and such partial understanding could lead to students inadvertently damaging devices during experimentation.

In contrast, circuit simulation, a very effective tool from the standpoint of learning and time commitment, is used sparingly. Engineering technology, unlike engineering programmes, does not emphasise analytical methods and does not typically demand higher order mathematical analysis using differential equations. Either or both of these instructional methods (simulation and analytical analysis) generally promote learning. [4] Hence, in this work, the authors introduced a three-step teaching and learning process by adding simulation assignments after the lecture, before the laboratory work.

Simulation is a useful tool that allows students to practice and understand the circuits at each component and each junction without damaging devices by mistake. In other words, theory, simulation and hands-on laboratory assignments are important and course design should consider all three components effectively. After completion of the hands-on experiment, students compare their results with the theoretical calculations and simulation data. The results can differ since each device has different characteristics. Each group modifies the device property parameters obtained from the experiment, then, calculates and analyses the circuits again as shown in Figure 1. In this process, students can further strengthen their theoretical knowledge and correlate simulation and circuit measurements.

It is important for technology and engineering educators to be aware that students need to have balanced instruction that allows for inquiry, practice and visual reinforcement. This can be accomplished through hands-on skill development and modern computer-based technologies to help students become effective learners and meet their future career goals [5]. In this study, the three-step teaching and learning concept was employed and tested to obtain students' feedback of their perceived learning gains. The students' feedback informed the authors as to whether the approach undertaken had helped students achieve the expected learning outcomes.

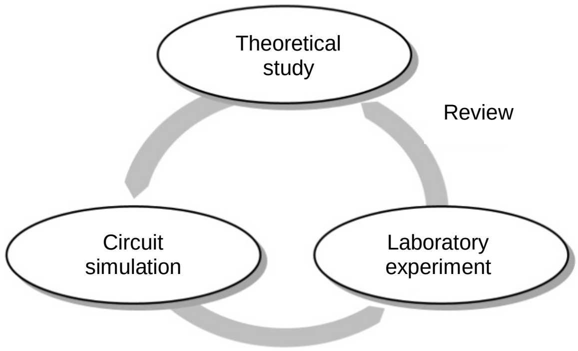

Figure 1: The three-step teaching and learning process model.

THE THREE-STEP TEACHING AND LEARNING PROCESS

TECH 4372 (Electronic Devices and Circuits), is a required three credit senior-level course that is offered in the fall semester. Topics covered include rectifier circuits, bipolar junction transistor (BJT) amplifier circuits, op-amp circuits and temperature sensing systems. These are relatively advanced circuits that are important for engineering technology and sound recording majors. There are two time slots allocated for this course in a week, two hours for the lecture and two hours for the laboratory. The laboratory houses electronic components and equipment for the characterisation of various circuits. The space and equipment are adequate for conducting hands-on practical laboratory assignments. However, the students were barely able to apply the theory covered in the lectures for measurement of electric circuits.

The two-hour laboratory class was sometimes not enough to complete the laboratory assignment since the students were not familiar with the equipment and the process for measuring points. In order to allow a smoother transition, circuit simulation was added into the teaching structure, so that the students could review and understand the operational principles, while also virtually practicing the laboratory experiments through the simulation activities. This modified three-step teaching and learning process was conducted in a senior level electronics course, TECH 4372, which is required for sound recording technology students and serves as an elective for technology management students.

THE STUDY

According to Sagor, action research is *...a disciplined process of inquiry conducted by and for those taking the action. The primary reason for engaging in action research is to assist the* actor *in improving and/or refining his or her actions* [6]. In this case, the researchers are also course professors and the three-step learning process introduced above is the central focus of an action research effort to cause an impact on student learning. The research questions explored by this study are:

- Question 1: can the three-step learning process be employed while still ensuring that all other curricular demands are met?
- Question 2: how is the student learning process affected if this method of instruction is implemented?

The methodology used was a case study supplemented by post data collection using an opinion survey of the methodology and student course assessment results. Twelve students participated in this study; seven students were from the sound recording technology programme of the School of Music and the remaining five students were from the engineering technology and technology management programmes of the Department of Engineering Technology at Texas State University.

One of the course assignments is focused around the design of a voltage divider biased BJT amplifier shown in Figure 2. The objectives of the assignment are: 1) to understand the applications and purpose of the BJT amplifier; 2) to analyse the electrical properties of the designed BJT amplifier; 3) to measure AC and DC voltages in a common-emitter amplifier; and 4) to obtain measured values of voltage amplification. Students are provided lectures on analytical modelling of the circuit and are expected to work alone in regard to the design BJT amplifiers using theoretical analysis and commercial circuit simulators. The three-step teaching and learning process was used as described in this study [6].

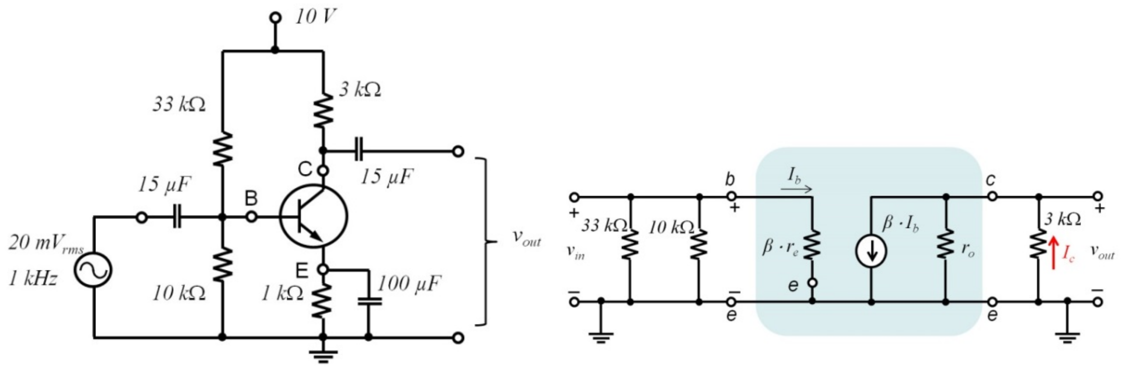

Figure 2: Voltage divider biasing BJT amplifier and equivalent r_e model of the amplifier [7].

Step One: Classroom and Basic Theory

Since each laboratory assignment takes almost two hours to complet, the simulation portion is scheduled to take place in the two-hour lecture class. During the lecture, background information is shared regarding the purpose of the circuits, methods of their analysis and a presentation of various circuit configurations. Students are encouraged to tap into their prior knowledge using relatable contextual examples. For instance, the circuit shown in Figure 2 is commonly called *voltage divider biasing* configuration for AC signal amplification.

A 20 mV_{rms} signal at 1 kHz is applied to the BJT amplifier. The purpose and advantage of this biasing are explained and the roles of electric elements, such as resistors and capacitors are discussed based on the knowledge of the pre-requisite course, TECH 2370, titled *Fundamentals of Electronics and Electricity*. Students analyse the circuits step-by-step in class. If necessary, the lecture introduces the equivalent modelling circuits shown in Figure 3, since this circuit is crucial in analysing the voltage gain of the amplifier. The next step involves circuit simulation.

Step Two: Circuit Simulation

The simulation of circuit performance enables students to gain expertise in designing real circuits and promotes self-learning as they are provided with immediate feedback by the software. It allows the students to determine the integrity and efficiency of a design before the circuit is physically constructed. Students configure their designs by connecting alternative components without physically building the circuits. Making these configurations in a simulation environment reduces the overall cost and time of building the electrical circuits. Simulation is very effective in teaching or demonstrating concepts to students. Students can *see* how the input signals are consumed and processed by each component in the circuit and comprehend the dynamics of circuit behaviour.

Today, students can access free and open source circuit simulators, which can be used for circuit drawing, design and analysis; e.g. NgSpice [8], LTSpice [9], etc. PSPICE is a licensed circuit simulator and is widely used by many professionals for electric system design and analysis [10]. MultiSim is simulation software for electronic design engineers and academic professionals, developed by National Instruments [11]. National Instruments also provides a student version of MultiSim with limited access. Many educational institutions are increasingly using computer aided learning packages as an alternative to hands-on practical laboratories.

Students proceed to undertake simulation activities in groups of two students after theoretical instruction. An instructor assists students if required. The simulation is conducted using MultiSim 12. Figure 3 shows the captured images generated with MultiSim 12 of the circuit in Figure 2. The students are required to submit reports after completing their simulation; a template for this report is provided by the instructor. This report helps students compare and reconcile their simulation results with the theoretical information gained in the lecture, facilitates reflection on the part of the students, and promotes better understanding of the design process.

Step Three: Conducting the Laboratory Experiment

After simulation, students proceed to construct the circuits physically and to study the response using *live* electrical signals in real time. This hands-on experiential learning helps reinforce theoretical concepts and appears to empower students by giving them a sense of accomplishment.

The experiential learning experiences enable them to apply the knowledge gained in the course to other situations never encountered, thereby, facilitating their application skills. The hands-on practical laboratories are conducted in the second lecture slot for two hours after completing circuit simulation. The actual parameter values are recorded before building circuits. Figure 4 shows the actual circuit on the breadboard and measuring instrument. The result of the experiment is then compared with that of the simulation and theoretical analysis.

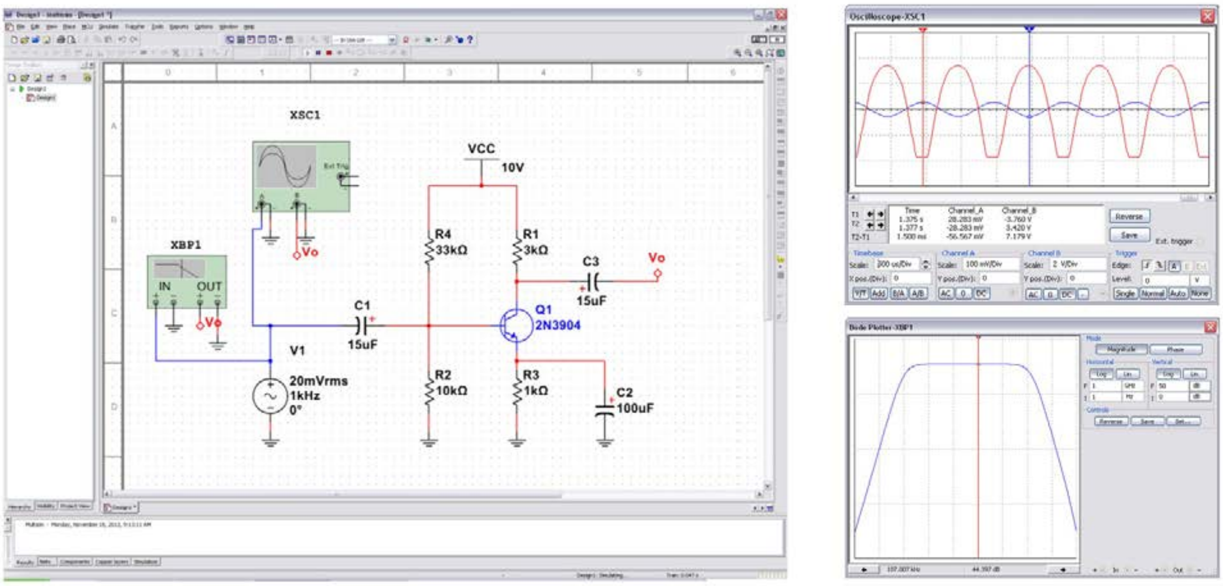

Figure 3: MultiSim 12 simulation windows of Voltage divider biasing BJT amplifier and simulation results.

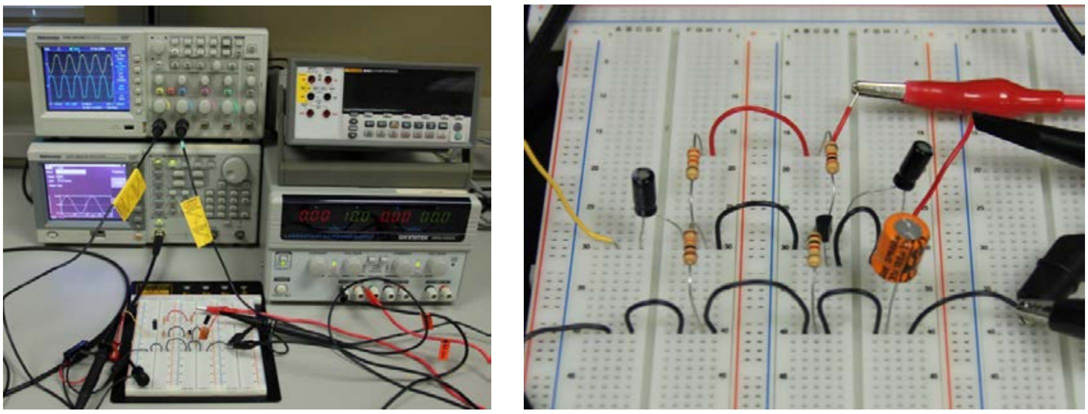

Figure 4: Circuit measurement setup for voltage divider biasing BJT amplifier and constructed circuit.

STUDENTS' PERCEPTIONS

The 12 students included in this study were enrolled for TECH 4372 in the Fall of 2013. All student participants had gone through all three steps on every key concept. They received lecture-based class room instruction first, simulated the circuits and, then, conducted the real laboratory experiment on a breadboard using electrical instruments. At the conclusion of each key concept, the students submitted a simulation report and a comprehensive laboratory report. All of the students were given a set of survey questions to evaluate their impression of the three-step teaching and learning concept to obtain feedback. The Likert-based survey was used. The questions included are displayed below.

- Q1: Theoretical study (lecture) helped you understand how the circuits work.
- Q2: Circuit simulation helped enhance your understanding of theoretical concepts.
- Q3: The ability to change parameters in circuit simulation helps you to further your knowledge.
- Q4: You are comfortable with using circuit simulation software.
- Q5: Lab experiments helped you to enhance your understanding of theoretical study.
- Q6: You are comfortable with building circuits and using electrical instrument.
- Q7: The time allocation (70 min. lecture/40 min. simulation/110 min. lab) is sufficient for you to understand the subjects.
- Q8: You feel that you are actively involved in the activity.
- Q9: Two per group is sufficient to discuss and complete simulation/lab assignments.
- Q10: Computational simulation can replace the hands-on lab exercise.

The survey was structured to gain insight into students' perceptions regarding the effectiveness of circuit simulation for class. The study results are shown in Figure 5. The numbers show the degree of student concurrence with the statements of survey questions using the scale, 1 - strongly disagree, 2 - disagree, 3 - neutral, 4 - agree, 5 - strongly agree. The mean values are indicated with dots and the error bars represent standard deviations. Due to the small sample size, this study used descriptive statistics collated from the survey results.

The students in the class responded favourably to the question relating to the effectiveness of lectures (Q1). The lecture helped students understand the operating principles and analyse the basic circuits. Students had practiced similar examples in and after class as home assignments. As shown in the students' feedback, the mean response of 4.67 indicates that students felt the lecture material was effective in enabling them to understand how circuits work.

No students in the class had previously learned or used the simulation software. However, all of them were comfortable using the simulation software after practicing with it for home assignments and simulation assignments (Q4). Students also found that actively modifying the component values during simulation provided better comprehension of the circuit designs (Q3). One question was prepared to assess students' opinion on whether simulation can replace the laboratory as a learning tool for electronics courses (Q10). The majority of the respondents disagreed that simulation can fully replace the hands-on laboratory exercise. 33% of students answered *neutral* and 42% of students marked *disagree*. Hands-on laboratory experiment was still important for fully understanding the theoretical concepts despite the circuit simulation helping them understand theoretical analysis (Q2 and Q5).

On the issue of time allocation, the mean response of 4.08 indicates that the students felt the lecture, simulation and laboratory exercise were optimised time-wise (Q7). None of the student groups completing the simulation had difficulty doing so in less than thirty minutes, but two of them commented that they preferred a longer simulation module. The size of teams is always an issue when students are required to carry out simulations or laboratory exercises. Students were arranged into groups of two. Three questions were formulated to assess opinions of group size (Q6, Q8 and Q9). According to the feedback, the mean values of Q6, Q8 and Q9 are 4.5, 4.5 and 4.58, respectively, indicating that this group size was deemed effective by the students.

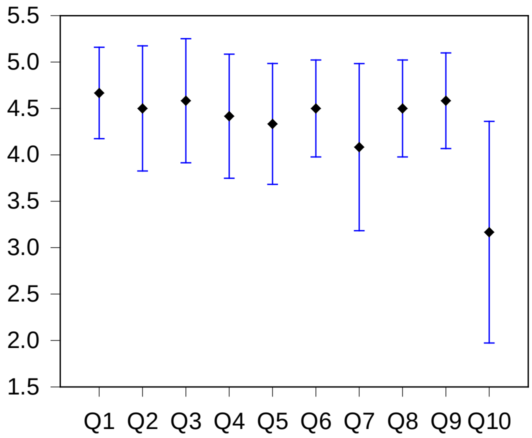

Figure 5: Students' feedback (1 - strongly disagree, 2 - disagree, 3 - neutral, 4 - agree, 5 - strongly agree).

CONCLUSIONS

In the three-step method, students are provided with a theoretical understanding of circuit design and analysis through lectures; they, then, independently confirm the lecture coverage using a simulation environment; finally, they receive hands-on exposure to physical circuit design through laboratory experimentation. Allowing students to manipulate and simulate circuit behaviour quickly accelerates their understanding of the principles provided in lecture. The physical construction of the circuits ensures that students maintain a realistic understanding of the design process and the limitations present outside the simulation environment.

To evaluate the importance of each step in the three-step method, a questionnaire was distributed to trial student participants. Students reported that the theoretical lecture helped them understand the circuit components and this understanding was enhanced when combined with circuit simulation. The participant feedback revealed that although complex circuits can be cleanly visualised and understood through simulation and computational tools, they cannot replace experience in the laboratory environment. The feedback indicates that each module (lecture, simulation and experimentation) in the three step method complements the others, and a balance of these components is required for effective learning. The addition of simulation assignments clearly helped to bridge the understanding between theory and physical circuit realisation.

In future considerations, a larger sampling size could improve statistical resolution. Sampling multiple classes with differing time allotments for each step of the three-step method could be analysed to evaluate the proper balance between lectures, simulation and experimentation. The feedback questionnaire could also benefit from expansion to reflect the students' learning through pre- and post-assessment of concept knowledge more accurately.

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