

A NEW PEDAGOGY IN ELECTRICAL AND COMPUTER ENGINEERING: AN EXPERIENTIAL AND CONCEPTUAL APPROACH

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Abstract *¾ This paper reports on an experimental program for educating high-school and beginning-college students in ubiquitous areas within Electrical and Computer Engineering (ECE). The unique aspect of this program is that it teaches advanced engineering topics using concepts and relevant experience rather than high-level mathematics, thus making many subjects normally reserved for the sophomore and junior year ECE curricula accessible to high-school and beginning-college students. The course has lecture and laboratory components, with topics selected and experiments designed to demonstrate their real-life relevance. Students in the pilot program succeeded in their laboratory work, and approximately 50% demonstrated high proficiency on college-level exam problems. Student evaluations of the program reflected a high level of satisfaction.*

Index Terms *¾ electrical and computer engineering education, electronics, laboratory, retention.*

INTRODUCTION

Technology permeates virtually all aspects of modern society. With the current rate of advance in applied science, and the previously unmatched level of our dependence on its products, it is helpful that every student achieves a basic level of understanding and appreciation of technology. In the course of training students in basic skills, it has thus become important to teach the fundamentals of electronics and computer structures at the onset of the 21st century, just as it has been with chemistry, physics, biology and mathematics in the latter half of the 20th century [1]. In addition, as with any field, Electrical and Computer Engineering is always in need of qualified students to become the next generation of engineers. Early exposure to the concepts of engineering is an effective method of drawing in prospective students.

To help satisfy these emerging pedagogical needs, we have developed a new teaching methodology for educating high-school and beginning-college students in the areas of Electrical and Computer Engineering (ECE). The unique aspect of this approach is that it emphasizes the teaching of advanced engineering topics using concepts and relevant

experience rather than high-level mathematics. By emphasizing hands-on laboratory work and qualitative description, many advanced topics, which are normally reserved for the sophomore and junior year ECE college curricula, can be presented to high-school and beginning-college students. While the treatment of these subjects for comprehensive professional training naturally requires the accompanying mathematical proficiency, we found that the descriptive approach, without detailed mathematics, is effective for giving students a conceptual anchor early-on in their technical training. This anchor should also provide an initial condition from which deeper mathematical treatments can be pursued and assimilated, and thus should help improve student retention in technology-related fields.

We applied this methodology under the auspices of the Maryland Governor's Institute of Technology, a living-learning program for selected high-school seniors sponsored by the State of Maryland. In the Summer of 2001 we designed and implemented the first ECE Technical Program for this Institute at the University of Maryland, College Park. This living-learning program lasted five weeks, with daily lectures and laboratory sessions. We found that the students responded favorably to the methodology. They successfully used the knowledge obtained in the lectures and laboratories to complete approximately 25 experiments, design a simple central processing unit (CPU), and fabricate high-fidelity audio amplifiers that they took home at the end of the program.

PROGRAM GOALS

To help fulfill the new educational demands for high-tech literacy in the 21st century, we designed the Electrical and Computer Engineering technical program with the following goals in mind.

- To present the students, who might not have had any prior background, with an enjoyable introduction to the fundamentals of Electrical and Computer Engineering, at a conceptual level similar to that of a high-school advanced placement course.
- To provide a conceptual background that serves as a foundation on which to build a deeper, more analytical

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study of the subject later in a student's education, and thereby maximize retention.

- To give students who might elect to enter ECE the advantage of an early presentation to this material.
- To give the students hands-on experience in the laboratory, which will be valuable in their later college and post-college careers.
- To demonstrate how the Electrical and Computer branch of engineering contributes to our way of life.
- To provide the students with relatively more solid information on which to base their future career choice.
- To make the material accessible to students with various learning styles.
- To gauge the effectiveness of a conceptual and experiential, rather than mathematical, approach to elementary electronics and computers for beginning students.

SYLLABUS DESIGN

The course consisted of laboratory sessions and lectures, supplemented by a textbook written by the course designers [2]. To achieve our aforementioned goals, we selected key topics tailored to cover, without going into too much theoretical detail or derivations, basic electronic components, the manner of using them, their applications, and fundamentals of analog signal operations and digital electronics. In a sense, the course was a distillation of several sophomore- and junior-year courses [3], simplified for the beginner audience. Among the topics covered by the course are the following (with associated chapters in the text):

1. An overview of Electrical and Computer Engineering: branches and subjects.
2. Basic concepts in electrical physics and circuit theory: charges, electric fields, potential, capacitance, resistance, direct currents (DC), alternating currents (AC), Ohm's Law, Kirchhoff's Laws, and semiconductors.
3. Basic concepts in the mathematical representation of signals: sinusoidal signals, amplitude, frequency, trigonometric representation, frequency components in signals and superposition.
4. PN-junction diodes: rectification, AC/DC conversion, light-emitting diodes (LEDs), and photodiodes.
5. Operational amplifiers: comparators, amplification, inverting-, non-inverting, and summing amplifiers.
6. Filters and filtering: active and passive high- and low-pass filters.
7. Bipolar junction transistors: current and voltage amplification.
8. A basic hi-fi audio amplifier: signal and power amplification, the concept of loading, power transistor usage, and heat sinks.

9. Digital logic and digital circuits: Boolean algebra, truth tables, AND and OR gates, combinational logic examples, sequential logic, and a simple adder.
10. Computer technology: standard computer architecture, programming languages, and a simple CPU design.
11. An arcade laser game design and implementation: phototransistors, revisiting comparators, and computer interfaces.

To maximize the students' assimilation of the material, the presentation forged immediate links to the real world for every component of the syllabus. Some examples of these links are given below:

- The concept of electric field was covered within the context of cathode-ray tubes.
- In contrast with the abstract presentation of trigonometry in high-school courses, we directly related trigonometric functions to observable physical quantities in both sound and vision. Sinusoidal signals, their frequency and amplitude features, were demonstrated on the oscilloscope, and by musical notes of different pitch and loudness. The presence of different-frequency components in signals was illustrated by references to the different tones of musical instruments and the human voice, and was observed visually on the oscilloscope.
- On the subject of pn-junctions and rectification, students were made aware of the link to real-world power supplies that virtually every household appliance uses.
- The summing amplifier experiment illustrated why operational amplifiers are "operational" amplifiers, with mention of the other, deeper applications of that sort.
- The filtering section found its immediate use in the tone control circuit (a primitive equalizer) for the audio amplifier, as well as the bipolar junction transistor section in the construction of the amplifier's output stage.
- Supplementing the lessons of these individual subject headings, the topics of operational amplifiers, filtering and bipolar junction transistors were emphasized, demonstrated and brought together under the auspices of the capstone project of the course, which was the high-fidelity audio amplifier.
- The section on digital logic opens with the design of an electronic vending machine. This is followed by the students building an actual circuit that performs addition.
- An expansion of this idea was presented with a demonstration of a primitive calculator, which led the students to design a simple CPU, with the fundamental architecture in use today: the memory, the flow-control circuit, the arithmetic-logic unit and the bus structures.

Hands-on learning and continual demonstration of the presented subjects were deemed extremely significant to enable obtaining a more solid grasp of the material. Consequently, experiments were designed to go with every part of the course. In the design of experiments and demonstrations, a very important consideration was to make sure that the outcomes would provide some immediate sensory feedback to the student, thus contributing to the learning process on more than a purely intellectual level. For the demonstration of signal frequency, amplitude, and superposition principles mentioned above, for instance, the instructors made use of a signal generator-oscilloscope-microphone-speaker setup, with a German recorder and human voice. The comparator and level indicator experiments for the operational amplifier section were designed to have multicolored LEDs as the output stage. The relationship between voltage, resistance and current was also illustrated in experiments where students could gauge the current level in a branch by the brightness of an LED, in addition to measuring and calculating the current. LEDs also served as the 1/0 binary indicators in digital circuit examples. Photonics and optical communication were illustrated with a game utilizing a laser-pointer, photodiodes and a computer interface that buzzed and kept score whenever the laser was accurately aimed at a photodetector.

IMPLEMENTATION

Twelve students from different Maryland high schools attended the program. As a result of the selection process, the student body was representative of an entering freshman class in ECE at the University of Maryland. The academic program was based on a five-days-a-week structure, with lectures and lab sessions scheduled almost every day.

Logistically, the lecture component of the program followed a relatively standard format, with a professor lecturing and students asking questions. However, from the lecture content perspective, it was nonstandard. Instead of discussing general theory, the lectures focused on technological applications that would later be verified in the lab. Within this context, we followed the syllabus described in the previous section. For each subject, the mathematics was kept at the high-school level. The course required algebra and trigonometry. Calculus was not used. In keeping with the conceptual approach, the lectures provided descriptions of device and circuit operation and applications, rather than rigorous derivations.

A dedicated laboratory was established for this program. The laboratory contained setups consisting of an oscilloscope, a signal generator, a DC power source, a multimeter and a circuit prototyping board. Through performing the experiments associated with each topic of the syllabus, the students had the chance to practically observe the concepts and applications mentioned in the lectures and to gain experience using the laboratory equipment.

Students worked in pairs, a relatively standard arrangement for sophomore and junior ECE lab classes, except for the part of the course where they each fabricated a hi-fi audio amplifier individually. The lab sessions typically lasted from two to three hours. Some experiments took more than one day to complete, while others were grouped together, with two or three performed in the same day. One exception, as will be described below, was the period in which the students put together their hi-fi amplifiers.

The students were given empty lab report templates for each experiment that they would fill in and return. These templates served as guidelines for what they were aiming to observe at each experiment. This facilitated the process of becoming proficient with the lab equipment and procedures.

The main project of the course was the construction of individual audio amplifiers by each student, which were designed to be fitted in a box, which they took home with them. During the prototyping, testing, and the final construction with the soldering iron, the students rose to the challenge, staying long hours on their own volition, and generally turning in high-quality end products!

To complement the technical lectures, the course included several co-curricular modules, expanding the program content beyond the lectures and labs. The co-curriculum enhanced the learning experience by strengthening the students' mental connections with diverse applications, providing motivation and contributing to confidence by indicating to them how much they already know. The charter class modules we implemented introduced issues in biotechnology and artificial intelligence. Short, accessible video presentations sparked active, hour-long discussions. In addition to the site trips organized by the University's liaison with the Institute, we also took the students through a tour of a laser sensor laboratory, giving them the chance to observe lasers in operation and light confinement inside a fiber optic cable.

PROGRAM OUTCOMES

The effectiveness of the program was evaluated through the implementors' observations, one exam, and student comments. Student impressions were sought about particular aspects of the course, as well as their thoughts about the course in general. Several focus groups were conducted by an educational psychologist. At the end of the course, a survey was conducted in which the students were asked to rank how much they agreed or disagreed with several statements describing the course and its components. The following describes outcomes of these studies.

- *Relating ECE to Daily Life.* The students reported that they were now better able to identify the applications of ECE in daily life, and that they have a better appreciation and understanding of the most common applications. For some, this feature was one of the highlights of the course. We have also observed that the students responded more enthusiastically to the

more solidly relevant experiments that yield results that they can relate to directly, as with the audio amplifier construction, the primitive CPU design and the optical arcade game. In the survey, most of the students strongly agreed that “they learned applications of electronics” and “increased their overall knowledge of technology.”

- *Hands-on Approach.* The laboratory received almost unanimous acclaim from the students as their favorite part of the experience. While the students were building their own hi-fi audio amplifiers to be taken home at the end of the course, they worked with enormous intensity, routinely staying in the lab to work after hours. The survey results indicate that the students strongly agree that “wiring and actually soldering [this system] was worth the time and energy” and agree that “it was exciting to observe my audio system work.”

From an ECE educator's point of view, the students' early exposure to the practical aspects of ECE education, notably to the usual practical problems encountered in the typical laboratory session with the equipment, components and prototype board, is also an advantage, even though the students specifically mention not enjoying those incidences. However, the students who eventually pursue an ECE degree will have the advantage of having encountered the possible problems before.

- *Advantages of Immediate Rewards.* The implementors observed that the concepts and portions of the course the students grasped most easily and quickly were those that involved experiments with an immediate, sensory feedback in addition to that provided by an oscilloscope trace. An example was the experiment to demonstrate the inverse relationship of current and resistance that utilized the brightness of an LED in series with the resistor, which aided rapid student comprehension.
- *The Course Level.* Student reactions to the course level varied, depending on their physics and mathematics backgrounds. Compared to high-school courses, they found the lectures more fast-paced and challenging. While some felt that even the elementary mathematical content was not trivial, most found it within their grasp, and almost all approved of the way the contents focused on the concepts, instead of the mathematics, of the technology involved.
- *Impact on Post-Secondary Education.* The course helped some of the students have a clearer idea about what paths they want to take for the next step in their education. There were students remarking that seeing the material helped them make more informed decisions, whether they decided they were interested in pursuing an ECE degree or they decided they were not. In the survey results, students agreed or strongly agreed that they would “want to study and learn more about the subject matter.”

- *Kolb Learning Style Assessments.* Early in the course, the implementors administered the Kolb Learning Style Inventory to the students. Approximately half of the students tested as Convergers under that system, while the others tested as Assimilators. This is the usual breakdown of preferences in the sciences and engineering, where students often prefer learning abstract concepts either by concrete examples and methods, such as laboratory assignments (Convergers) or by observing others conduct experiments or by interpolation and extension of existing knowledge (Assimilators) [4]. Indeed at the end of the period, it was observed that students from both learning styles appeared to benefit equally from the program. It is the implementors' contention that the parallel lab/lecture structure contributed to this positive outcome, with the lab appealing to the Converger learning style and the lectures to the Assimilator learning style. Since the other Kolb learning styles (Divergers and Accommodators) were not represented among this group of students, we cannot determine whether this course structure would similarly benefit these individuals.

- *Student Achievements.* From the beginning, the course relied on the students' self-motivation to learn. This being a noncredit program, no grades were assigned. However, to help monitor the students' progress, a 1.5-hour test was administered at the end of the third week of the course. The test covered the analog electronics sections of the course. The results were remarkably favorable. About half of the students scored above 90 % on this test that included questions that could have been on sophomore or junior level class midterms in ECE. Example questions are presented in Figure 1.

In keeping with the students' enjoyment of the lab component of the course, they performed well also in the laboratories, completing some 25 experiments within the allocated time and each assembling a functional audio amplifier, completely packaged as a unit and usable with their household audio equipment.

- *General Responses in the Student Survey.* The results of the student survey indicated that their impressions were very favorable. In general, students strongly agreed that “the program was a worthwhile experience” and that they “would recommend the program to others.” For the most part, they found the subject matter challenging, but not all of them indicated that they worked hard and applied themselves at a level equal to the challenge level. Still, again for the most part, appealing to the self-motivation of the students in a non-credit program like this seems to have worked.

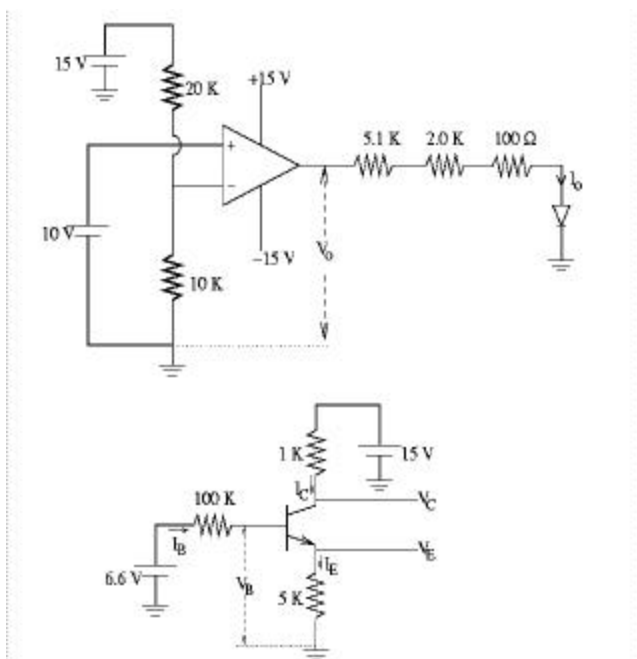


FIGURE 1

SAMPLE MIDTERM EXAM QUESTIONS. The questions associated with the circuits are the following:

- Top circuit: For this op-amp circuit, what are I_o and V_o ? Is the LED on, why or why not?
- Bottom circuit: For the BJT circuit $\beta=100$ and V_{BE} . Draw the DC equivalent circuit. Calculate I_B , I_E , I_C , V_B , V_E , and V_C .

CONCLUSION

We have developed and implemented a curriculum for teaching high-technology areas of electronics and computer architecture to high-school and beginning-college students. By concentrating on concepts, as opposed to mathematics, we have been able to convey material that is usually reserved for college sophomores and juniors. The combined lecture/hands-on approach was highly successful for connecting with students of different learning styles.

Students reported their satisfaction at building a real-life application that actually works after their experience of fabricating a hi-fi audio amplifier. Even though there was no formal pressure on the students because we did not assign grades, one-half of the students scored approximately 90 % on a mid-term exam. We found this extremely encouraging, especially since this student evaluation included questions that could have easily been found on exams given to ECE sophomores and juniors.

We found the course aided students to relate better to the applications of Electrical and Computer Engineering in daily life, and to arrive at more informed decisions about their choice of study for post-secondary education. We also expect that students who have taken the course to be significantly more prepared to handle the more abstract mathematical rigors required in higher level college

technology courses, and thus help improve retention rates for engineering students.

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