Session

A CONCEPT INVENTORY TO PROBE STUDENT UNDERSTANDING OF BASIC ELECTRONICS

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Abstract

We have developed a concept inventory that probes student understanding of basic electronics. The concept inventory consists of twenty-five multiple-choice questions that can be answered by a junior electrical engineering student in approximately ten minutes. Each entry in the inventory is written in language that is accessible to a literate public. The working hypothesis was that most of the students would be familiar with these concepts through exposure in lower division electrical engineering, calculus, and calculus-based physics coursework. In selecting the concepts, we drew upon the Dictionary of Cultural Literacy to validate that the majority of the concepts are truly essential to a broad grasp of popular science and technology. Our practice has been to administer the inventory at the beginning and end of the semester to cadres of students that enrolled in an analog electronics course. We will present data collected over the last two semesters to illustrate major misconceptions and significant gains obtained through the course.

1. Introduction

ABET 2000 student outcome criteria stress the need for assessment of student learning using instruments other than proverbial midterm and comprehensive examinations. Nationwide, engineering faculty are addressing this need and considering assessment tools including pre-post knowledge evaluation, one-minute essays and student portfolios. Pioneering work in the area of pre-semester and post-semester knowledge assessment has been utilized to demonstrate the effectiveness of active learning. The force concept inventory[1] is an example of this type of assessment tool. More recently, this type of assessment has demonstrated that student learning improved via the implementation of a learning community environment in an experimental junior-level electrical engineering curriculum[2]. Our intent is to develop and test a concept inventory that incorporates fundamental concepts in electronics and to utilize this tool for continuous quality improvement of a traditional electrical engineering curriculum.

From a higher level learning perspective, the two main purposes of the proposed electronics concept inventory are:

- to define the key information (i.e. concepts) that is important for electrical engineering students to understand and remember; and
- to assess the level of understanding of this key information.

Each entry in the proposed inventory is written in language that is accessible to literate individuals. Although few lay individuals may be familiar with all of the concepts, the working hypothesis is that most of the students participating in the study would be familiar with these concepts through exposure in lower division electrical engineering, calculus, and calculus-based physics coursework. We rely on the reading ability of students tested but do not pose questions in a visual or alternative format.

2. Background

UTEP serves a large binational, bicultural student population on the United States-Mexico border. The student population closely mirrors the demographics of El Paso, from which the university draws more than 90 percent of its students. Practically all students are daily commuters and 81 percent are employed. Moreover, 69 percent of them are Hispanic and 54 percent are the first ones in their families to pursue a college degree. Similar statistics hold true for our engineering majors.

The electronics concept inventory is administered to junior electrical engineering majors who enroll in the first of two junior-level electronics courses (Electronics I). Enrollment is capped at 28 students per semester. Most students who take this course are concurrently enrolled in the second course of the electric networks sequence. Electronics I is taught in a formal cooperative learning format[3,4]. Class time is divided into 10-minute lectures with team activities in between. Teams of four are formed during the first week of the course. Team membership is considered permanent for the duration of the course. The passing rate (C or better) with this teaching format is close to 90 percent.

Electronics I is divided into four modules starting with an introduction to signals, their spectra and amplifier models. The next module deals with diode models, rectifiers and regulators. The third module is devoted to the analysis and design of bipolar junction transistor amplifiers. The last module introduces the field effect transistor and basic circuit applications. In all there are 27 learning outcomes in which students must show proficiency. These learning outcomes are highly correlated to the a-k ABET 2000 student outcomes. A well-known textbook is the required reference for Electronics I[5].

3. Discussion

The inventory is a multiple-choice questionnaire that probes the students' understanding of fundamental concepts relevant to electrical and electronic engineering. In selecting the questions, we drew upon the Dictionary of Cultural Literacy[6] to validate that the majority of the concepts are truly essential to popular science and technology. In our opinion this reference serves as a synopsis of a core body of western hemisphere Humanistic knowledge.[1] At the same time it presents an intellectual challenge to all Americans to make sense of current scientific research and technological developments.

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[1] We do not intend to address issues regarding the undeniable Eurocentric nature of the reference, which has raised criticism in some academic environments.

The 25 questions (Appendix A) are presented in no discernible order but can be arranged in the following general categories:

- I. Electric charges and fields (Questions 16, 18, 20)
- II. Current and voltage laws (Questions 1, 8, 21, and 22)
- III. Electronic network components (Questions 6, 7, 9, 11, 15, 23, 24, and 25)
- IV. Signals and systems (Questions 2, 3, 4, 5, 10, 12, 13, 14, 17, and 19)

In the first category, students answer questions about the nature of the electron and its behavior in an electric field. In the second category, students choose the best definition of current and dynamic resistance and the purpose of the voltage and current divider. The third category tests students on the purpose of the resistor, capacitor, inductor, transformer, diode, transistor and power supply. The last category probes students on issues regarding signal shape, amplitude, frequency, spectrum, audio region, and the decibel scale.

The inventory is offered to students twice, preferably during the first and last week of the semester. Students are advised that although there is no grade associated with the inventory, the answers they provide become part of a formal on-going study to improve student learning. Most students manage to answer all questions in less than ten minutes. No student is given access to his or her scores but may see cohort results at the end of the semester.

4. Results

Over the last two semesters, we have consistently administered the inventory to two separate student cohorts. Figure 1 shows the data for the Fall 2001 cohort (n=24). In this case, students showed an improvement in overall understanding but there appeared to be four problematic questions. Significant gains above 30 percentile points were observed for the following concepts:

a) The resistance across two points is the rate of change of the voltage with respect to the current (Question 1).
b) The spectrum of a signal shows all of its components as a function of frequency (Question 5).
c) The semiconductor diode is a device that behaves like an electronic switch (Question 6).
d) The transistor is a device that behaves like a current amplifier (Question 7).

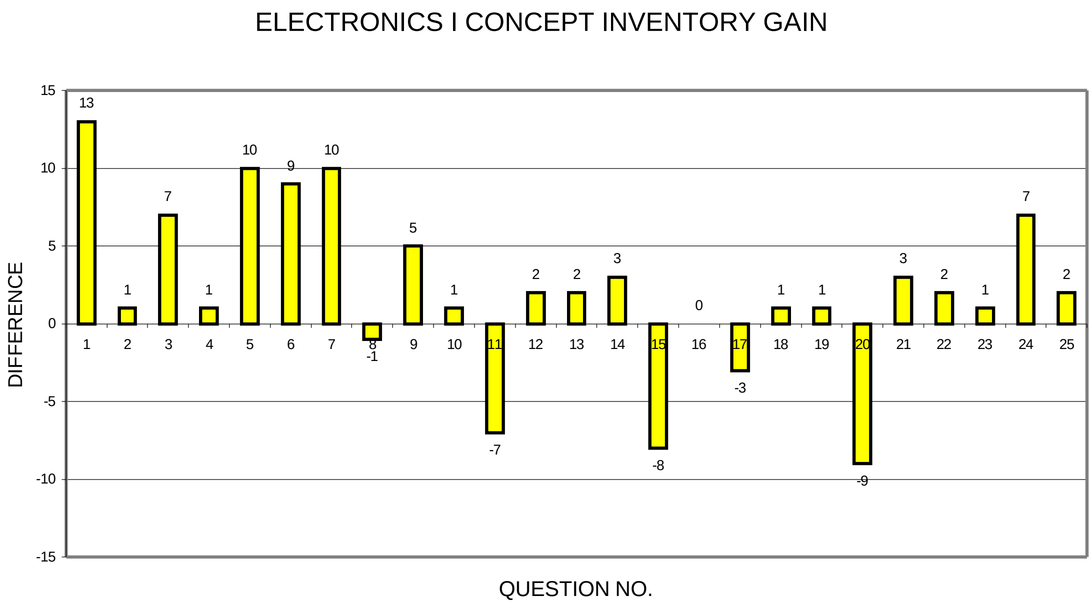

Figure 1. Gain for Fall 2001 Student Cohort (n=24)

At least 80 percent of the students in this cohort discerned the following concepts at the end of the semester but could not do so during the first week of classes:

a) In practice, a filter circuit eliminates frequency components from the input signal (Question 3).
b) The spectrum of a signal shows all of its components as a function of frequency (Question 5).
c) The transistor is a device that behaves like a current amplifier (Question 7).

Surprisingly, there was considerable confusion with respect to four concepts:

a) The battery is a device that produces an electric current (Question 11).
b) The ideal transformer transfers electric energy (Question 15).
c) The decibel is a unit of sound volume (Question 17).
d) Electrons flow from negative to positive potential (Question 20).

Although each of these questions was under a different category, the percentage of students that missed them was significant and the underlying topics may require special attention in future offerings of the course.

Figure 2 shows the data for the Spring 2001 cohort (n=25). As in the case of the Fall cohort, students in the Spring cohort showed an improvement in overall understanding.

ELECTRONICS I CONCEPT INVENTORY GAIN

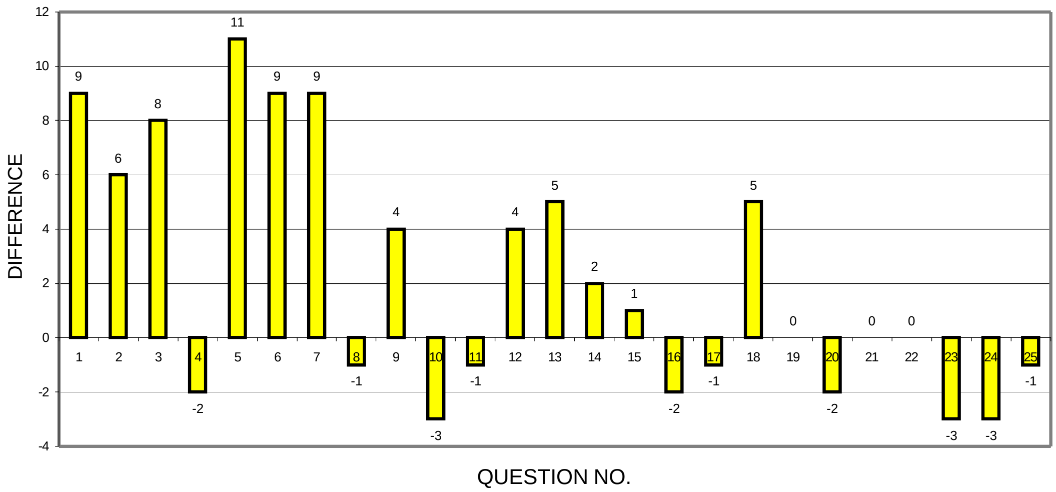

Figure 2. Gain for Spring 2001 Student Cohort (n=25)

Significant gains above 30 percentile points were observed for five concepts:

a) The resistance across two points is the rate of change of the voltage with respect to the current (Question 1).
b) In practice, a filter circuit eliminates frequency components from the input signal (Question 3).
c) The spectrum of a signal shows all of its components as a function of frequency (Question 5).
d) The semiconductor diode is a device that behaves like an electronic switch (Question 6).
e) The transistor is a device that behaves like a current amplifier (Question 7).

At least 80 percent of the students in this cohort correctly identified the correct answers for the following concepts at the end of the semester but could not do so during the first week of classes:

a) The semiconductor diode is a device that behaves like an electronic switch (Question 6).
b) A radio amplifier increases the amplitude and changes the phase of the input signal (Question 2).

On the other hand, there was moderate but widely spread confusion with respect to concepts under categories I, III, and IV. Notice, however, that each of these questions was under a different category, suggesting that students had a basic grasp of concepts in all categories.

Table 1 gives a statistical perspective for recent concept inventory scores. For the Fall 2001, the median increased by 2 (8.3 percentage points). The average increased by 2.5 (10.4 percentile points) while the standard deviation slightly decreased. For Spring 2001, the median increased by 3 (12 percentile points). While the average increased by 2.3 (9.2 percentile points), the standard deviation remained essentially the same.

Table 1. Inventory Score Statistics

Semester	*Median*		*Average*		*Standard Deviation*	
	Pre	Post	Pre	Post	Pre	Post
Fall 2001 (n=24)	15	17	14.3	16.8	4.1	3.5
Spring 2001 (n=25)	15	18	15.1	17.4	2.8	2.7

As Figure 3 indicates the performance of student cohorts over the last two years has been consistent. This suggests that, on average, students move on to the next course in the electronics sequence, Electronics II, with a good grasp of fundamental concepts.

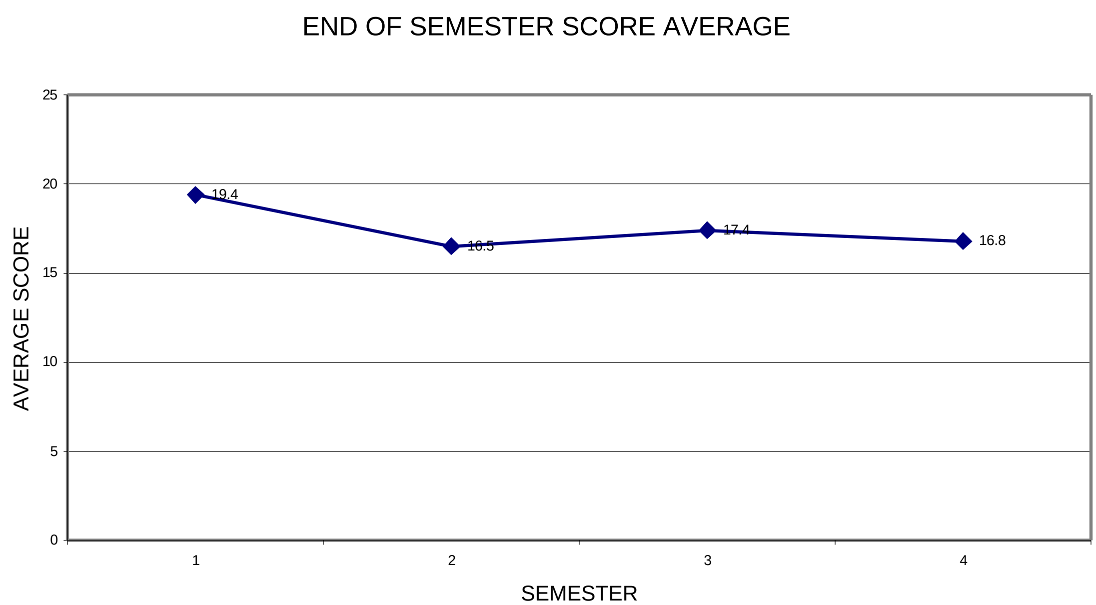

Figure 3. History of Concept Inventory Average (End of Semester Results)

5. Conclusions

The electronics concept inventory proved to be a valuable tool for student learning assessment in a junior-level electronics course. This instrument allowed us to gauge the extent of fundamental knowledge students had in the area of electronics at the onset of the course. Furthermore, the instrument allowed us to quantify the gain in understanding after a semester of active learning activities. Our primary finding is that, on average, end-of-semester student performance has been consistent.

Future work will include additional items for some question categories to make their analysis statistically significant. Since most students are visual learners, there is a need to address differences in learning styles. We intend to use graphics to test conceptual learning via visualization. Once these items are tested we will extend the use of the course inventory for cross-institutional gender and ethnic studies.

6. Acknowledgements

This work was funded by the National Science Foundation's Model Institutions for Excellence Program under cooperative agreement No. EEC-9550502. One of the goals of the MIE Project at UTEP is to improve the effectiveness of teaching and learning of Hispanic science and engineering majors.

References

1. David Hestenes, Malcom Wells, and Gregg Swackhamer, "Force Concept Inventory," The Physics Teacher, vol. 30, pp. 141-151, 1992.
2. Ronald J. Roedel, S. El-Ghazaly, Teri Reed Rhoads, and E. El-Sharawy, "The Wave Concepts Inventory - An Assessment Tool for Courses in Electromagnetic Engineering, Frontiers in Education Conference Proceedings, Tempe, Arizona, Nov. 4-7, 1998.
3. David W. Johnson and Roger T. Johnson, *Advanced Cooperative Learning*, Interaction Book Company, 1992.
4. Benjamin C. Flores and Connie Kubo Della-Piana, "Microelectronics - An Introduction to Formal Cooperative Learning," Frontiers in Education Conference Proceedings, Tempe, Arizona, Nov. 4-7, 1998.
5. Adel Sedra and Kenneth Smith, *Microelectronics Circuits*, 4th Edition, Oxford University Press, 1998.
6. Eric D. Hirsch, Jr., Joseph F. Kett, and James Trefil, *The Dictionary of Cultural Literacy*, 2nd. Edition, Houghton and Mifflin Company, 1993.

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Appendix A: Electronics Concept Inventory

1. In general, if the voltage between two points is a function of the current through them, the resistance across these points is the rate of change of the voltage with respect to the current.
2. In practice, a radio amplifier increases the amplitude and changes the phase of the input signal.
3. In practice, a filter circuit eliminates frequency components from the input signal.
4. A radio amplifier is said to distort a sinusoid if the signal changes in shape.
5. The spectrum of a signal shows all of its components as a function of frequency.
6. The semiconductor diode is a device that behaves like an electronic switch.
7. The bipolar junction transistor is a device that behaves like a current amplifier.
8. An electric current is the flow rate of charge as a function of time.
9. In practice, a DC power supply changes an alternating current into a direct current.
10. An RC circuit can be used to smooth out a signal.
11. A battery is a device that produces an electric current.
12. An audio signal has frequency components between 100 Hz and 20 kHz.
13. The frequency of a monotone signal is the number of peaks or valleys per second.
14. An alternating current changes its direction periodically.
15. The ideal transformer transfers electric energy.
16. The electron is a fundamental particle-wave with a small mass that occupies energy orbitals near the nucleus of the atom.
17. The decibel is a unit of the volume of sounds.
18. An electric field is directly proportional to the acceleration of an electric charge.
19. Household current in the US is 60 Hz.
20. Electrons flow from negative to positive potential.
21. A voltage divider uses resistors to split the voltage between them.
22. A current divider uses resistors to split the current between them.
23. A capacitor stores electric energy.
24. An inductor stores magnetic energy.
25. A resistor converts electric energy into thermal energy.