AC 2004-1210: IN-CLASS DEMONSTRATIONS TO MAKE ELECTRICAL CIRCUITS EASIER TO UNDERSTAND

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In-Class Demonstrations to Make Electrical Circuits Easier to Understand

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Abstract

The National Instruments ELVIS device allows the instructor to show circuit solutions in real time using real physical devices, with attendant uncertainties in component values, offset voltages, leakage currents, and noise. These demonstrations make the circuit behavior real during lecture rather than being completely a mathematical calculation, a distinct advantage for that subset of students whose learning styles are more practically based rather than conceptual. Students in a senior elective, Electronics II, were exposed to in-class demonstrations of lecture topics during the summer 2003 semester. Their reactions to changes in the learning environment were evaluated using survey responses. In general the response was positive with students' recognition of the value of in-class demonstrations to help them visualize concepts and with students advocating further use of ELVIS in other Engineering courses.

Motivation

One reason that students have a difficult time understanding the functional aspects of electrical circuits is that they are difficult to visualize: you can't see electrons, but you can see what they do in real devices. Grasping concepts like electrical circuits or even basic electricity is not an easy task for many students [1]. Engineering students' difficulties are often compounded by traditional instructional methods that fail to engage their thinking [2]. Instruction that goes beyond the traditional lecture / class notes model is needed to help students reason about topics that are not in their everyday experience and thinking. One instructional strategy that helps engineering students go deeper in their thinking about the functional aspects of electrical circuits is showing these effects through the use of real-time devices.

We have not been able to use real-time demonstrations in class effectively, and certainly not in our larger classes. A real-time prototyping and development system that is an ideal teaching aid, called ELVIS (Electronics Laboratory Virtual Instrument Suite) [3] has been developed by National Instruments (Austin TX). This apparatus uses real circuit devices on a breadboard connected to a PC through ADC (Analog Digital Conversion) hardware and virtual instruments (on the PC) to display the results of circuit measurements in real time. The instruments are realized completely in software and represent a nearly complete instrument suite, including arbitrary waveform generators and noise sources. The hardware can be connected to a standard laptop PC over its PCMCIA bus, and can thus be simultaneously projected onto existing classroom video systems. This allows the instructor to show circuit solutions in real time using real physical devices, with attendant uncertainties in component values, offset voltages, leakage currents, and noise. With ELVIS, circuit behavior can be seen by students during lecture rather than only described as a strictly mathematical calculation or numerical simulation. In an article advocating the use of ELVIS, a professor of engineering noted in particular its benefits as an instructional aid for varied levels of circuit theory, "We could teach analog circuit analysis and electronic circuit theory very effectively using this system. With the use of the Bode analyzer, which can be used to quickly characterize the frequency response of an arbitrary circuit, more advanced courses such as digital signal processing would benefit from its use, as well."[4]

Figure 1: Picture of ELVIS unit with prototyping board and external probes attached.

As an example, Figure 1 is a photograph of the ELVIS plug-in prototyping board (green) installed on the base unit (white). The removable prototyping board can be populated off-line and inserted into the base unit for measurement. The protoboard is designed to be owned by individual students and is appropriately sized, and has holes for, a standard three-ring binder. The base unit provides power supplies, fixed and variable, function generation (sine, square, triangular), and hardwired ports to the multimeter, oscilloscope and waveform analyzers (Bode plotter, spectrum analyzer, arbitrary waveform generator). Figure 2 is a typical transistor curve trace for a 2N4401 (npn, small signal) from the three-wire V-I diagram virtual instrument.

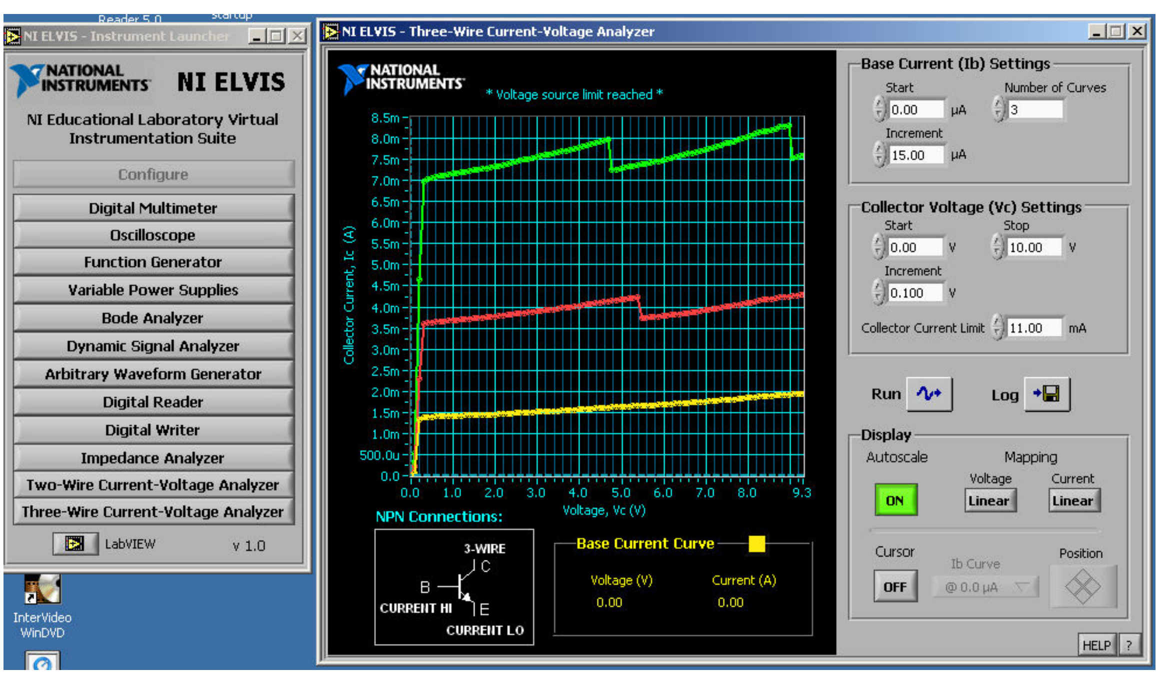

Figure 2: Curve trace for a 2N4401 small signal transistor using the 3-wire V-I Analyzer

In Figure 3, a typical oscilloscope screen shows the gain and phase shift in a common emitter amplifier of gain –10, made from the 2N4401 in Figure 2. The lower amplitude channel (blue) is the input signal, and the higher amplitude channel (green) is the applied output voltage at a nominal frequency of 50 Hz.

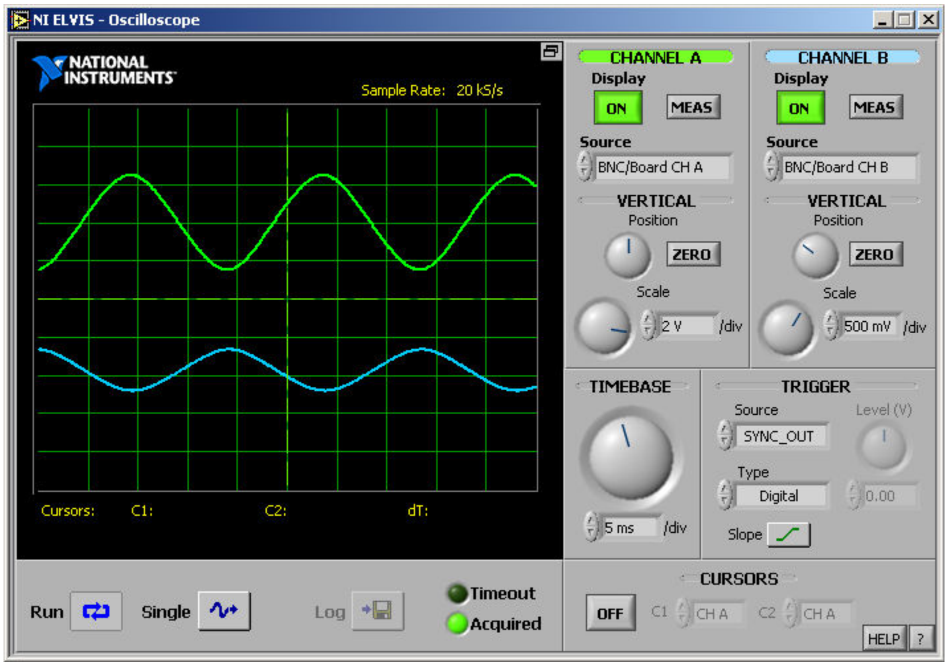

Figure 3: Common emitter amplifier output from ELVIS Oscilloscope module.

The major logistical advantage of this system for the instructor is that it combines 12 major measurement devices into one box, minimizing the difficulties of transporting a demonstration to the classroom. While ELVIS offers full testing, measurement, and data saving capabilities and students can use it for hands-on learning in the laboratory, it is also an effective tool for instructor-led classroom demonstrations. Research on teaching suggests that these four clusters of instructional skills and approaches promote students' achievement:

- Organizing and explaining materials in ways appropriate to students' abilities
- Creating an environment for learning
- Helping students become autonomous, self-regulated learners
- Reflecting on and evaluating their teaching[5].

With these strategies in mind, ELVIS was employed during lectures for real-time demonstrations of circuit performance in a second electronics class, EE 338K (a junior/senior level elective with 20 students) in the College of Engineering at the University of Texas at Austin in the summer 2003 term. The experienced faculty member (JP) was aware of the perplexing nature of the topics for many students and he wanted to integrate ELVIS into his lectures in order to help students visualize concepts that are more traditionally taught using only mathematical formulas and to give them a context for theoretical background that was covered. To assess the impact of ELVIS in the lecture environment, two University specialists, one an instructional designer in the College's Faculty Innovation Center (KS) and the other a faculty member in statistics and research from the College of Education (NB), conducted a review of this process by gathering observational data, student perceptions, faculty insights, and achievement data.

Course description

The particular class studied was a senior elective for students of Electrical Engineering, *Electronic Circuits II*, the second class in the electronics sequence (part of the "circuits" area in the EE curriculum). The first class, *Electronic Circuits I* (required), emphasizes analysis and design with discrete devices in both discrete forms and as building blocks in integrated circuit form. The domain of *Electronic Circuits II* is board-level electronics design: operational amplifiers, feedback topologies, filters, oscillators, timers, and power amplifiers.

Formal Instructional Objectives: At the conclusion of this course the student will be able to:

1. Design and/or analyze circuits using Operational Amplifiers to solve the specified problem, including non-ideal amplifier characteristics.
2. Create (derive) a simplified bilateral two-port linear model of the feedback configuration given an operational amplifier circuit, including non-ideal amplifier characteristics.
3. Determine the relative stability (Gain Margin and Phase Margin) of a given a closed loop amplifier circuit and the open loop transfer function for the forward amplifier.
4. Design and/or analyze an oscillator circuit (Wien-bridge, Colpitts, class "C", relaxation timer) and be able to describe the operating principles of each oscillator toplolgy.
5. Design and/or analyze a high power circuit (DC power supply, class "A", class "B", class "AB", switching circuit using diodes or SCRs).

Study background

At question is “do in-class instructor-led demonstrations using ELVIS help to facilitate student understanding and help them to capture the concepts or are they just time-consuming "cute" additions which give students a break during lecture?” In order to address this question, a number of instruments and approaches were used. Students’ attitudes and perceptions regarding their learning needs and ELVIS’ impact on them were gauged by pre- and post-instruction questionnaires as well as the final course evaluation. Additionally, students responded to a learning styles inventory in order to be able to describe the types of learning style preference of the participating students. Finally, student achievement data (final course grade) was summarized.

Learning styles are seen as an extension of personality and personal style or type and are measured by self-report of preference rather than measured by tasks of differentiate abilities. That is, learning styles are a group of constructs, such as learning style, cognitive style, and personal style, which reflect natural genetic inclinations representation of innate biological origins[6]. According to Kolb, learning styles are not fixed personality traits, but the result of unique individual programming[7].

While students will differ as to their preferred learning styles, a person’s professional orientation (due to training and a common set of values and beliefs) can shape learning styles. There is currently much discussion of learning styles in engineering education and one self-scoring online instrument called the Index of Learning Styles[8] (ILS) is frequently used. This scaled instrument classifies students according to how they receive and process information and assesses their preferences on four dimensions (active/reflective, sensing/intuitive, visual/verbal, and sequential/global) of a learning style model formulated by Richard M. Felder and Linda K. Silverman. The online instrument was developed by Richard M. Felder and Barbara A. Soloman of North Carolina State University. Along with the learning style model, a parallel teaching model is provided that classifies instructional methods by how well they address the proposed learning style components. While students may appear to demonstrate a particular style over time, this style is generally not stable and students' ability to draw on multiple strategies for different tasks distinguishes good and poor learners.

Evaluation instruments

Students were asked to fill out a questionnaire on the first day of class. This questionnaire included some demographic questions. In addition, the survey included some open-ended questions designed to assess students' pedagogical experiences in science/engineering classes. A couple of these questions were designed to assess the students' understanding of which and how certain pedagogical strategies seemed to enhance their learning.

Students were also asked to fill out a questionnaire on the last day of class. On this survey, students were prompted, using open-ended questions, to describe the instructional techniques that had been used in the course. They were also asked to describe how those activities had impacted their mastery of the course material including specific questions designed to assess the impact of the use of ELVIS on their learning and interest in the concepts covered.

Course evaluations were used here to describe how the students had responded to the course in general. (The same course evaluation was used as is required for every course on campus). This evaluation form includes eight Likert-scale items and one open-ended item. The prompt for the open-ended item was:

> "In many ways your written comments can be the most important part of your evaluation of the course and instructor. In the space provided, please indicate what aspect of the course content and instruction were best, how the instructor could improve his or her teaching, and how the content of the course might be improved. The instructor will receive this form after the semester is over."

Six of the Likert-scale items had response options ranging from a score of one for "Strongly Disagree "to five for "Strongly Agree", while response options for two of the items ranged from a score of one representing "Very Unsatisfactory" to five for "Excellent." Higher scores on the items indicated stronger evaluations of the course. Table 1 lists the multiple-choice items included in the survey (and the associated mean item scores for the course). This post-test also included the ILS survey to assess the learning style preference of participants.

Table 1
Course Evaluation Questions and Average Item Scores for Multiple-Choice Items

Item	Mean Item Score
1. Course well-organized.	4.2
2. Communicated information effectively.	4.4
3. Showed interest in student progress.	4.8
4. Assignments and test returned promptly.	4.4
5. Student freedom of expression	4.4
6. Course of value to date.	4.7
7. Overall Instructor Rating	4.5
8. Overall Course Rating	4.3

Analyses

Summary statistics were provided to describe responses to the demographic questions and to the ordinal- and interval-scaled items. Responses to the open-ended questions on the pre- and post-tests were summarized qualitatively. Common themes underlying responses were sought and then summarized using verbal description.

Findings: demographics

Table 2 lists the demographic information describing the 19 students who filled out the pre-test questionnaire. As can be seen, the students enrolled in the course represent a pretty typical upper-level Engineering course although the proportion of females seemed somewhat higher than average for an Electrical Engineering course. Seventeen of the 19 students were seniors and 16 students completed the class.

Table 2
Demographic information describing Students

Gender	
Male	15 (79.0%)
Female	4 (21.0%)
Ethnicity	
Caucasian	10 (52.6%)
Asian	5 (26.3%)
Hispanic	3 (15.8%)
African-American	0
Other	1 (5.3%)
Average Age	23.0
Average GPA	3.15
Average Final Grade in Course	3.13

Findings: learning styles

Scores on the ILS scale are forced-choice in that respondents must choose between one of two options, for each item, that best describes them. Patterns of responses are then assigned scores on each of the four bipolar dimensions being assessed. The scores on each dimension that result indicate the strength of the respondent's preference for the relevant end of the dimension. These scores can range from -11 to +11. Positive scores reflect preferences for the second pole of the relevant dimension. The greater the magnitude of the score, the stronger is the reported preference.

For example, a student might be assigned a score of +11 on the Active/Reflective dimension. This means that the respondent has a very strong preference for Reflective learning and would most likely have great difficulty in Active learning scenarios. A score of -7 on this dimension however would indicate that the respondent would have a moderate preference for Active learning and would encounter difficulties in a Reflective learning environment. In general scores between one and three reflect pretty well-balanced preference between the two dimensions. Scores of five to seven reflect a moderate preference for the relevant pole. Scores between nine and eleven reflect a strong preference. (Only odd-numbered scores can result).

Table 3 contains the mean and standard deviation of the students' scores on each of the four dimensions for the students in this course. These values indicate that on average, most students were well-balanced on the Active/Reflective, Sensing/Intuitive and Sequential/Global dimensions. Most of these students, however, tended to be somewhat Visual rather than Verbal learners which matches the pattern typically found for Engineering students. [9]

Table 3
Statistics Describing Students' Learning Styles

Learning Style Dimension	Mean (*SD*)
Active/Reflective	1.875 (5.16)
Sensing/Intuitive	-1.375 (4.51)
Visual/Verbal	-3.875 (4.90)
Sequential/Global	.875 (4.41)

Findings: pre-test questionnaire

On the pre-test, students were asked to respond to a question assessing whether they had had courses that included classroom demonstrations as well as a question that asked about how those demonstrations had impacted their learning. Students noted that two facets of in-class demonstrations positively impacted their learning, including: hands-on activities and small group work. Hands-on activities were cited by several students for helping them really understand concepts: "It certainly helps to understand what we're supposed to work on better when we apply what we learn." In addition, applying the concepts that had been introduced was also found to enhance the students' retention of the concepts: "Application of knowledge lasts longer than pure memorization."

Given the predominance of the visual learning style associated with most engineers, it seems imperative to ensure the learning style environment of engineering classrooms matches that of the students. It seemed (as was noted by several of the students) that hands-on demonstrations seemed to help them *visualize* concepts traditionally taught using only mathematical formulas: "Software demo's help to show things that are hard to visualize from equations." And thus, hands-on pedagogical activities appear to provide a good match to the needs of engineering students. From a motivational standpoint, students also noted that hands-on activities made learning "more exciting" and "more interesting" than the traditional lecture format. One negative comment was brought up by a student with reference to in-class activities. The student felt that such activities can put "a lot of pressure on the students. I feel that activities should be planned for outside of class, if at all."

While the students' mentioning the importance of small group work to their mastery of material is not of direct relevance to this investigation of the use of hands-on demonstration software, it is still of importance as a footnote for engineering educators. It seems that students feel the primary benefits of small group work include the realization of the "importance of teamwork to make things work" and the enhance comfort and safety associated with the potential "to bounce ideas off of" fellow team members.

Students were also prompted to indicate which kinds of instructional activities had helped them learn in previous science engineering classes. Similar responses were given to those provided in response to the earlier survey questions (with specific reference to classroom demonstrations). The importance of small group work and of the enhanced opportunities for visualization was again emphasized as well as the heightened interest in the material that would result. As noted by one student, "I will be more interested and instead of coasting through a lecture, I might pay attention more."

Findings: post-test questionnaire

On the post-survey, students were asked to describe how the activities/materials in the class affected their learning. Of the various methods (lecture, homework, demonstrations), the students were most influenced by two aspects: quality lectures and in-class demonstrations. This class was taught by a seasoned veteran in the classroom and his ability to provide good lectures was not an issue explored in the survey questions, but several student comments do suggest that if a demonstration is to build student understanding during a lecture, the lecturer needs to be able to guide students as to what is relevant. “ELVIS was helpful in that we actually could see what was going on in the waveforms instead of having a static graph in the book. Dr. Pearce’s explanation while the demonstrations were going on was helpful.”

These students are upper-division electrical engineering students and can be reflective about their metacognitive (thinking about one’s thinking) skills. From their responses on the question, “How did the use of ELVIS in this class affect your learning?” it is apparent that they are aware of the value of real-world applications and visualization tools in helping them to understand complex and abstract topics. One student simply noted, “It helped to understand the concepts…more than explaining could ever do.” Actually seeing some of the properties real-world devices helped them to comprehend, “ELVIS gave me a clear view on how certain electronic circuits behave.” Not only can ELVIS display information but it can demonstrate how “theory actually applies to actual set-up.”

These students’ learning styles indicated a preference for visual learning and seeing “how the concepts can be applied” was found to be beneficial. There were some frustrations, however, when ELVIS was not working correctly. Class time goes by quickly and students did not want to spend time with something that was not functioning. One student advised, “Make sure it works! “ They also were asked if ELVIS “affected interest in the material covered?” The students found that it did and in fact, one wrote that it had sparked interest in learning other topics. One student was so enthusiastic that, “It made me go out and buy $100 worth of components to try and build some of the things we did in class.”

The students were asked if they had any advice that could enhance the use of ELVIS in other ECE classes. Most of the responses suggested ways that would get students more involved in their learning. For example, one wrote, “Explain the circuit fully on the board and have us determine what the response should be, then use ELVIS to see what the actual response is.” Another suggested, “Have handouts of the circuits you are going to do with blank spaces for the students to fill in the graphs.”

Findings: course evaluations

Only thirteen students were present to fill out the course evaluation. Table 1 contains the mean item scores for each of the eight multiple-choice items of interest on the UT course evaluation. With each of the mean item scores exceeding a value of four on the one-to-five scales (with higher scores representing better evaluations), this data support the success of the course. These ratings are the highest that this same instructor has received for any of the courses that he has taught over the last few years. In addition, when comparing average scores on the two most important general questions that address the overall ratings of the instructor and of this specific course, this instructor’s performance was in the top two of the seven different professors who have taught this class in the last three years.

The students’ responses to the open-ended question were generally positive with three of the thirteen students noting specifically that this was the course they had enjoyed best in college to date. Those students who made comments about the pedagogy employed mentioned the benefits of ELVIS and MultiSim (a simulation package) being used and that it improved their learning. Only one student commented that “I feel Multisim provided the same learning experience as ELVIS without the hassle.” It should be noted, however, that this was the first time that the professor had used ELVIS in his class and some of the hassles of first using the tool should be overcome in ensuing courses.

Conclusions

In conclusion, ELVIS has been shown to be an effective adjunct to traditional lecture-based instruction, in that it is a visual tool well-matched to the predominantly visual learning style in the class. A substantial subset of the students was positively impacted by the real-time demonstrations. The instructor was very satisfied with the improvement realized by the addition of this device to the classroom. Subsequently, ELVIS has also been used in two sophomore circuit analysis classes (one for ECE majors and the other a service course for Biomedical Engineering and Chemical Engineering majors) and also in a senior elective, *Medical Electronics*. The electric circuit phenomena demonstrated have the "ring of truth" since all of the components are physical, with the encumbent uncertainties, rather than idealized.

Nevertheless, there are significant logistical disadvantages to the use of ELVIS in the classroom, most of them traceable to "cockpit error" on the part of the instructor, but frustrating nonetheless. First, it is not at all certain that the PC display system will connect benignly to the classroom video system. In at least one classroom the "Display Your Laptop" input took over the PC and prevented use of ELVIS. The "Auxiliary Video Input" off of the rear video output port is much to be preferred. In our experience the PC often had difficulty finding the ADC card — this problem is easily solved by disconnecting and reconnecting the ADC card (until you hear the "beep"), but caused considerable delay and frustration, on the part of both the students and instructor. It is imperative to test the system in the actual room in which the class will take place prior to class starting.

Second, the instructor absolutely must have all planned demonstrations worked out in detail in advance. Due to limitations in sample rate, the frequency response of the ELVIS tool is generally limited to the audio range. In order for the Bode Analyzer demonstration to be effective, for example, one must see at least two decades both above and below the pole(s); so the pole frequency must be carefully placed to make an effective illustration. Additionally, the input impedance of the Bode Analyzer terminals is not particularly high, so when using resistors above about 500 k_ in L-section filters the loading effects are substantial: buffer amplifiers solve this. The Curve Tracer (v-i diagram tool) is easy to use with resistors; but when a diode is used the maximum applied forward voltage must be very carefully set. A disadvantage of the diode curve demonstration is that the ELVIS power supplies are not generally capable of applying sufficient inverse potential to visualize the breakdown region, except for zener diodes, of course. Currently, the minimum sweep rate of the oscilloscope tool is much too fast to display manual switching events (as in first- and second-order transient circuit analysis) or many important biopotential signals, such as the ECG.

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