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Enhancing Post-Covid Student Proficiency and Confidence in Using Laboratory Test Equipment

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Abstract – Because of the Covid-19 Pandemic during academic year 2020-2021, many of the classes and laboratories in our undergraduate Electrical Engineering (EE) program were conducted remotely, making tremendous use of videoconferencing technologies such as Microsoft Teams, and simulation engines such as National Instruments' MultiSim™. As we began to move back to "in person" learning for the Fall of 2021, our EE faculty observed some early weaknesses in student achievement of ABET EE student outcome #6 (an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions). We found that while students demonstrated excellent proficiency in using modern tools such as MATLAB™ and MultiSim™ (which had been used extensively during remote classes), they appeared considerably weaker in making independent measurements using laboratory hardware such as oscilloscopes, dynamic signal analyzers (FFT analyzers), RF analyzers, and even commonly used voltage and current meters (which had not been used much during remote learning).

Here we highlight specific student shortcomings we observed in laboratory skills as students began their in-person lab experiences during the Fall 2021 semester. We then discuss our approaches to remedy these shortcomings during the Fall 2021 semester to improve student confidence and proficiency in the use of laboratory instrumentation. We also highlight the improvements we saw in achievement of ABET student outcomes. While computer simulation has its place in undergraduate education, practical testing and measurement of electronic systems does require physical measurement and interaction using modern test equipment, and we identified some areas for timely improvement. Our focus in this paper is on improved student performance in using laboratory test equipment in Linear Circuits and Antennas courses. In the Linear Circuits course, students use the Oscilloscope and Dynamic Signal Analyzer to identify the characteristics of several op-amps and circuits (e.g, op-amp open-loop frequency response, gain-bandwidth product, slew rate, output impedance, closed-loop frequency response of an inverting amplifier), and in the in the Antennas course students use the RF analyzer to characterize the behavior of RF circuits, transmission lines and antennas.

We show how our increased emphasis on lab skills for the Fall 2021 semester, coupled with unique assessment tools, significantly improved achievement of student outcome #6. More specifically we share the successes we experienced in using oral individual quizzes during lab meetings, group classroom quizzes, individual student observation of setup and measurement, and adding questions related to lab skills and experiences on hourly examinations.

Introduction

During the Fall 2020 semester, most Electrical Engineering classes and labs at the U.S. Coast Guard Academy in New London, CT, were conducted remotely, because of the highly contagious and rapidly spreading COVID-19 virus. Like many other programs nationwide, we adapted quickly, and made extensive use of remote learning technologies to minimize impacts to student learning. For the most part our faculty and students used Microsoft Teams™ for virtual classroom meetings. Most student labs were shifted to a Microsoft Teams™ experience as well, and in many cases, we had to replace "hands on equipment" types of labs with "hands on keyboard" Matlab™ exercises, or National Instruments MultiSim™ circuit simulation exercises to teach fundamental concepts. Students did rise to the challenge, and assessment of student performance in our sophomore-level circuits courses for the 2020-2021 academic year, particularly for ABET Outcome 6, was acceptable. (Outcome 6: An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions.)

During our Electrical Engineering End of Course Reviews (EOCR's) held at the end of both Fall 2020 and Spring 2021 semesters, faculty reflected upon the impacts and challenges (both present and future) that remote learning had presented (or would soon create) for our students. In one discussion in Spring 2021 we noted that Fall 2021 labs in EE would likely be "in-person" and would require our new junior-level students to have a good working knowledge of laboratory test equipment (e.g. oscilloscopes, function generators, breadboards, digital volt-ohmmeters), be proficient in troubleshooting, and even require students to learn to use relatively unfamiliar equipment (Agilent 35670 Dynamic Signal Analyzers). At that point we considered that early assessment of Outcome 6 Performance Indicator #1 (develop *and conduct* an experimental procedure to test a hypothesis or characterize a system) would be warranted. That early assessment was done in lab during our junior-level course called "Linear Circuits," and based on those early results, we implemented significant changes to our lab content and pedagogy to emphasize (and assess) student troubleshooting and proficiency in using test equipment while conducting lab experiments.

Background

Considerable research on the learning effectiveness of online labs (either remote, augmented reality, or simulation) has been conducted in recent years [1]-[5], with more than 30 references provided in [4] alone. In [1] and [2], Taher and Kahn specifically compared simulation-based and hands-on methodologies in an engineering technology program and concluded that simulation alone was not as effective as hybrid or combinational instructional technologies for learning effectiveness. (In fact these researchers also used NI Multisim for their study.) Corter, et. al. [3] presented a model for testing relative effectiveness of remote, hands-on, and simulated laboratories, and although their study was limited in scope, results suggest that remote labs were comparable in effectiveness to hands-on labs, especially for learning basic applications of course content. In more recent work, May, et. al. [4] noted that the Covid- 19 pandemic necessitated a fast shift to “virtual labs” for many institutions, and their thorough background literature review suggested many benefits for online labs (including simulation). At the same time, they also commented that “researchers are at polar ends of arguments for and against the efficacy of online labs.” In fact, research by Ma and Nickerson [5] suggests that online laboratories are well-suited for teaching conceptual knowledge, and perhaps not as well-suited for teaching design skills.

Instead of focusing on design skills or concept mastery, here we focus on student ability to develop *and conduct* an experimental procedure to test a hypothesis or characterize a system. Since a student’s ability to conduct an experimental procedure is directly linked to that student’s proficiency and confidence in using laboratory test equipment, we became concerned when early assessment in Fall 2021 indicated that a number of students were having difficulties in configuring lab equipment.

Return to the “In-Person” Lab Experience Fall 2021

Beginning in the Fall of 2021 classes and labs in EE at the Coast Guard Academy did return to “in-person.” The first lab in the first week of the “Linear Circuits” course was entitled “Review of Frequency Response Concepts: Oscilloscope and Dynamic Signal Analyzer Measurements, MultiSim™ Simulation, and MATLAB™ Prediction.” One purpose of that lab was to review operation of the Digitizing Oscilloscope (Agilent DSO6034A) and Agilent 35670A Dynamic Signal Analyzer (DSA) while making frequency response measurements, and to compare measured results to theoretical frequency response measurements (from MATLAB™) and simulated results (from NI MultiSim™). Students first designed a simple 1st order low-pass filter (Figure 1) for a -3 dB cutoff at 800 Hz, and they constructed the circuit on a breadboard. Students then proceeded to use the Agilent 33220A function generator as a signal source, and recorded V_{out} and V_{in} (both magnitude and phase) on the circuit in Figure 1 using the Agilent DSO6034A Digitizing Oscilloscope over frequencies from 100Hz to 10kHz.

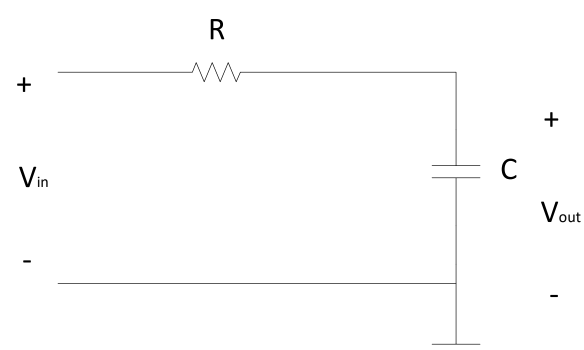

Figure 1. Simple first order low pass filter for Lab#1.

In Part 2 of this lab, students were asked to measure the frequency response (magnitude and phase) of the circuit shown in Figure 1, using an Agilent 35670A Dynamic Signal Analyzer, which inherently performs the frequency response measurement in the frequency domain. Instructions for measuring frequency response (using 2-channel method) were provided to each student, and they were expected to export the magnitude and phase response data to MATLAB™ for later processing. We did explain that in order to measure frequency response, they would need to connect the Agilent 35670A SOURCE output to Channel#1 plus the circuit V_{in} input. We also instructed them to connect Channel#2 to measure V_{out}. Final settings provided to the student were as follows:

Inst Mode	2 channel
Source	Periodic Chirp, with level $1V_{rms}$
Window:	Uniform
Meas Data	Freq Resp 2/1 (which performs vector division of ch2/ch1
Upper Trace Coord	dB Magnitude with logarithmic frequency axis
Lower Trace Coord	Phase (degrees), with logarithmic frequency axis
Trigger	Source

Table 1. Agilent 35670A configuration for measuring frequency response.

Students worked in pairs to make frequency response measurements in both time and frequency domains, where the maximum number of students in each of 2 lab sections was 10. During this lab each student was assessed by a faculty member who made observations on student ability to perform the experiment according to the rubrics shown in Appendices 1 and 2. Using those rubrics, we established an "Excellent-Adequate-Minimal-Unsat" determination (EAMU) [6] for each student in the class based upon a series of assessments, including (1) direct observation, (2) required level of instructor assistance in troubleshooting, (3) required level of assistance in instrument configuration, (4) individual student responses to instructor questions, and (4) instructor observations of measurement results. Composite results for first-week assessments in Lab#1 are summarized in Table 2.

Time domain/oscilloscope measurements: EAMU was (2,4,8,3)
Frequency domain/Dynamic Signal Analyzer measurements: EAMU was (4,4,6,3)

Table 2. First-week assessment summary from Lab#1 for Performance Indicator 6.1.

Based on this early information, we realized that in fact, this group of students was a bit weaker in lab skill proficiency than students we had taught in previous years. Of course, our hypothesis was that this was due to their limited "actual hands-on test equipment" experience from their two previous semesters. Although this hypothesis was never proved, it was clear that we had identified an early challenge, therefore we acted quickly so these students could experience success in much more advanced labs that were to come beginning two weeks later. Equipment used for signal measurement in Lab#1 and for more advanced labs to follow are shown in Figures 2 and 3.

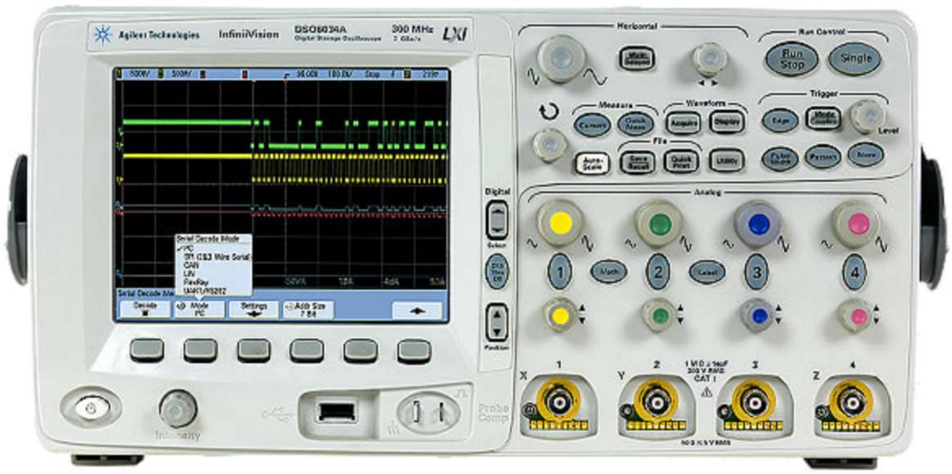

Figure 2. Digitizing Oscilloscope (Agilent DSO6034A) used in Linear Circuits labs.

Figure 3. Dynamic Signal Analyzer (HP/Agilent 35670A) used in Linear Circuits labs.

Challenging Measurements Required in Follow-On Labs

The more complex measurements we expected students to perform in subsequent labs focused on learning about real-world operational amplifier characteristics as compared to ideal operational amplifier assumptions [7]. Students were expected to conduct measurements on the μA741 (and in some cases, on the LM318) operational amplifier, including measurements of slew rate, gain-bandwidth product, open loop output impedance (and closed-loop output impedance in an inverting amplifier configuration), plus input bias and offset currents [7]. Subsequent labs also required that students design Sallen-Key (Case I) second order sections for Q=2 at two different resonant frequencies (differing by a factor of 10 in frequency), and measure the resulting frequency responses, to learn about gain-bandwidth product limitations in analog filter design. In order to make all these measurements correctly it was imperative that all students quickly become experts in using both the Digitizing Oscilloscope (Agilent DSO6034A) and the Dynamic

Signal Analyzer (HP/Agilent 35670A). We have found over the years that unless a student masters the test equipment, they become confused and frustrated very quickly, and when problems arise, they are unable to determine if the problem is in their instrument configuration (improper triggering, A/D range, signal source, window, etc.), their test configuration (probe not in the correct place, etc.), or if they have made an error in designing or building their circuit (incorrect wiring, or DC power not energized).

Innovative Changes to Teaching, and Assessment Used to Foster Improvement

Given that students had displayed some weakness in using test equipment in conducting the Lab#1 experiment, for the more complex labs, the first change we implemented for these subsequent labs was that we insisted that students not touch the Dynamic Signal Analyzer until they knew they had a "working circuit." That meant that we had to place special emphasis on getting all students to be comfortable in using the oscilloscope, and knowledgeable about test methodology. For instance, in measuring the frequency response of an active low-pass filter in the third week of the semester, we asked them to follow this logical configuration sequence:

(1) Configure the function generator to produce a low frequency sinusoid (e.g. 100Hz).
(2) Route the function generator output to Channel #1 of the oscilloscope.
(3) Configure the oscilloscope to display that sinusoid. (If students do not see the sinusoid, they have either not energized the function generator output, or have not configured the oscilloscope properly (i.e. verify that Channel#1 is turned on, triggering on that channel, and that trigger edge and level are set properly.)
(4) Once they have a proper display (and they know the oscilloscope is configured properly), then route the sinusoid to the circuit input, and put the scope probe on the circuit output. (If they do not see the sinusoid at that point, their circuit is not constructed properly, and they need to check wiring.) If they do see a sinusoid, they were asked to increase frequency of the input signal to verify that their circuit was behaving like the low pass filter they expected (i.e. decreasing amplitude with increasing frequency).
(5) Only after completing steps 1-4 successfully were students then allowed to disconnect the function generator and oscilloscope and begin to configure the Dynamic Signal Analyzer (DSA) according to a prescribed list of settings. At this point, if students are measuring the frequency response of some low pass filter and do not see the results they expect, they only need to check their DSA configuration, because they are already confident that they have a working circuit.

This (enforced) improved test methodology which we implemented for the early part of the Fall 2021 semester significantly reduced student frustration and improved student confidence.

A second change we implemented for subsequent labs was that we provided the students a "reference sheet" for configuring the DSA. We felt this was reasonable since it is a relatively complex instrument. Students initially very much appreciated this learning tool, however we found that that by the middle of the semester, students rarely needed to refer to that reference, as they had mastered operation of the DSA.

A third change we implemented for subsequent labs was that when students worked in pairs on the equipment, the faculty selected which member of the pair would be "pushing the buttons" that day, to configure the oscilloscope and dynamic signal analyzer. (Of course, each partner was allowed to "coach.") At first our students found this to be a bit intrusive, however they soon realized the benefit of this more active learning on the equipment. Faculty directly observed each student, asked questions (e.g. oral quizzes), and used the rubrics in Appendices 1 and 2 to assess individual student abilities.

A fourth change we implemented in class (which supported the lab) was conducting what we call "group quizzes." For a class of 17 students, we divided the class into 3 groups, and assigned one design problem to each group. We "extended" each class design problem to include lab-related topics. In the group quiz, each member of the group earns the same grade, and the faculty member selects who will present to the class (so there is tremendous incentive for every student to understand everything about the design!) The students chosen to present are allowed to select one member of their group in case they need to "phone a friend" during their presentation of the group work. Students generally loved this activity as they found they were fully invested and learned the material. One "group quiz" question asked students to imagine that they had found an op-amp in the lab, however no one could read any of the stamped information on the op-amp. Assuming it has the same pin-out as the uA741 op-amp, design an experiment to estimate the op-amp's gain-bandwidth product. (What test equipment, what signals, and what outputs would you measure, and how exactly would you determine the gain-bandwidth product?) A sample rubric for this assessment of this quiz is shown in Appendix 3.

Assessment Results – Improved Student Proficiency and Confidence

Just after mid-semester, students were assessed once again on the lab skills portion of Performance Indicator 6-1 (develop and conduct an experimental procedure to test a hypothesis or characterize a system). Faculty assessed students in lab based on direct observation and answers to questions by using rubrics shown earlier in Appendices 1 and 2. Tabulated EAMU assessment results are summarized in Table 3.

Time domain/oscilloscope measurements: EAMU was (12,4,0,1)
Frequency domain/Dynamic Signal Analyzer measurements: EAMU was (10,4,2,1)

Table 3. Post mid-semester assessment summary for Performance Indicator 6.1.

Similar improvement was noted while assessing Performance Indicator 6.1 on hourly examination #2, where students were asked in one problem to "design an experiment to measure an op-amp's slew rate characteristic." They were asked to be specific about what circuit they would use, what input waveform, what test equipment, and how exactly slew rate would be measured.

Conclusions

The Covid-19 Pandemic during academic year 2020-2021 presented some unique and significant challenges for all of us in academia. At the U.S. Coast Guard Academy, our EE sophomores performed many of their labs remotely, making use of videoconferencing technologies and simulation engines to learn many of the concepts normally taught as "hands-on equipment" style labs. When students returned in the Fall 2021 as juniors, we noted some early weaknesses in lab skill proficiency as part of our assessment of ABET Outcome #6. Immediately after the first lab meeting, we increased our emphasis of lab skill development in several ways and incorporated that development as a natural part of the execution of each (more complex) successive lab in their Linear Circuits course. Here we highlight the successes we experienced through using oral individual quizzes during lab sessions, group classroom quizzes, individual student observation of setup and measurement, plus adding questions related to lab skills to hourly examinations. We believe this increased emphasis resulted in significant improvements towards achieving ABET student outcomes (specifically Outcome #6) during the Fall 2021 semester.

Appendix 1: Rubric for initial assessment of Performance Indicator 6-1 (develop and conduct an experimental procedure to test a hypothesis or characterize a system), used while taking time domain measurements to determine frequency response.

Category	General Description	Score
Excellent	Able to configure equipment to make all proper measurements. Student clearly recognizes when a problem exists and is able to determine whether there is a problem in the circuit, a problem in the measurement device, or a problem in positioning of the measurement probes. Student offers multiple ways to begin the troubleshooting and is able to perform all troubleshooting processes independently. Is able to find and solve all problems. Able to recognize incorrect equipment configuration. Overall, student needed no assistance in order to accomplish lab procedure, and was able to work independently to perform troubleshooting. Student had few or no questions, and any questions asked reflected remarkable insight regarding troubleshooting capability.	100%-90%
Adequate	Able to make some of the proper measurements (perhaps magnitude response only). Student clearly recognizes when a problem exists, and is able to determine whether there is a problem in the circuit, a problem in the measurement device, or a problem in positioning of the measurement probes. Student offers several ways to begin the troubleshooting and is able to perform most of the troubleshooting process independently. Is able to find some (but perhaps not all) problems, and for those problems that remain, is able to narrow the problem down prior to instructor assistance. Able to recognize incorrect instrument configuration.	90%-75%
Minimal	Unable to make proper measurements, however student does recognize a problem exists. Student is able to determine whether there is a problem in the circuit, a problem in the measurement device, or a problem in positioning of the measurement probes. Student offers at least two ways on how to begin the troubleshooting, and is able to begin the troubleshooting process independently. Ended up identifying the wrong problem, or spent an inordinate amount of time troubleshooting such that instructor had to offer significant assistance in the troubleshooting process. May or may not be able to recognize incorrect instrument configuration.	75%-60%
Unsat:	Unable to make proper measurements. Student may not believe that a problem exists. Student may or may not be able to determine whether there is a problem in the circuit, a problem in the measurement device, or a problem in positioning of the measurement probes. Student may not be able to offer a way to begin troubleshooting, and is likely unable to begin the troubleshooting process independently. Student likely ended up identifying the wrong problem, or spent an inordinate amount of time troubleshooting such that instructor had to offer significant assistance in the troubleshooting process. Typically unable to recognize incorrect instrument configuration.	60%-0%

Appendix 2: Rubric for initial assessment of Performance Indicator 6-1 (develop and conduct an experimental procedure to test a hypothesis or characterize a system), used while taking frequency domain measurements to determine frequency response.

Category	**General Description**	**Score**
Excellent	Very minimal instructor assistance required on Agilent 35670A analyzer, and in troubleshooting circuit. Demonstrated complete understanding of expected results. Plots generated were complete, labeled, and scaled properly. In lab, students needed minimal assistance to accomplish lab procedure. Student questions reflected thorough understanding of laboratory work. Student exhibited complete understanding of test equipment concepts such as triggering modes, range, choice of input signals for frequency response measurement, etc.	100%-90%
Adequate	Only modest instructor assistance required for Agilent 35670A analyzer setup. No assistance required in building circuit, and modest assistance required in troubleshooting. Plots generated were generally correct but may not have been scaled correctly. Student generally understood what expected measurements should be. In lab, student needed only intermittent assistance to accomplish lab procedures. Student questions reflected significant understanding of laboratory work, with misunderstandings limited to more subtle or minor laboratory concepts. Student exhibited adequate understanding of test equipment concepts such as triggering modes, range, choice of input signals for frequency response measurement, etc.	90%-75%
Minimal	Demonstrated minimal ability to operate test equipment to perform desired measurements without significant instructor assistance. Significant instructor intervention required to set up the Agilent 35670A Dynamic Signal Analyzer (DSA). Minimal knowledge displayed regarding instrumentation scales; instructor intervention required. Displayed limited knowledge regarding what expected measurements should be. In lab, student needed constant assistance in order to accomplish lab procedure, and perhaps needed assistance in building circuit. Student questions reflected inadequate understanding of frequency domain measurements and significant misunderstandings of major concepts from lab work. Student exhibited minimal understanding of test equipment concepts such as triggering modes, range, choice of input signals for frequency response measurement, etc.	75%-60%
Unsat:	Demonstrated no independent ability to operate test equipment to perform desired measurements, and no knowledge of what the expected measurement results should be. Significant instructor intervention required to set up Agilent 35670 DSA and build circuit. No knowledge displayed regarding instrumentation scales, ranges, or triggering, rendering measurements unusable or of extremely poor quality. In lab, student had little idea what questions to ask. Student exhibited virtually no understanding of test equipment concepts such as triggering modes, range, etc.	60%-0%

Appendix 3: Sample rubric used for "group quiz" assessment of gain-bandwidth product measurement..

Category	General Description	Score (max 10)
Excellent (E)	Provided a very reasonable circuit for use in determining op-amp gain bandwidth product, and circuit would actually work. Student may or may not have specified exact component values. Instrument required for testing, the measurement itself (V_{out}/V_- , or "open-loop" frequency response), and choice of input waveform were all correct.	9-10
Adequate (A)	Provided a circuit for use in determining op-amp gain-bandwidth product, however circuit may not have worked. Instrument required for testing, the measurement itself (V_{out}/V_-, or "open-loop" frequency response), and choice of input waveform were all correct.	7-8
Minimal (M)	Provided a circuit for use in determining op-amp gain-bandwidth product, however circuit would likely not function as intended. Two of the following three were correct: Instrument required for testing, the measurement itself (V_{out}/V_-, or "open-loop" frequency response), and choice of input waveform.	6
Unsat (U)	Provided a circuit for use in determining op-amp gain-bandwidth product, however circuit would definitely not function as intended, and op-amp may not even have been used in the circuit! Either one or zero of the following three were correct: Instrument required for testing, the measurement itself (V_{out}/V_-, or "open-loop" frequency response), and choice of input waveform.	0-5

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