Objective structured exam for biomedical electronics

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Introduction

The assessment of engineering students enrolled in laboratory courses is usually based on reports that the students prepare after completing experiments in the laboratory. This practice encourages the development of technical writing and presentation skills that are necessary for preparing successful future engineers. However, the students abilities for analysis of a laboratory experiment, their manipulative skills in conducting measurements using laboratory instrumentation, and their thought process during debugging of a faulty setup are not adequately assessed with the laboratory report.

Six abilities have been distinguished for chemistry laboratories[1] that can be adapted to describe student performance in engineering laboratories:

1. Communication: identification of laboratory equipment and operations;
2. Observation: recording of observations and detecting errors in techniques;
3. Investigation: accurate recording of properties of a device or compound;
4. Reporting: maintenance of a suitable laboratory record;
5. Manipulation: skills in working with laboratory equipment;
6. Discipline: maintenance of an orderly laboratory and observation of safety procedures.

The laboratory report allows the instructor to assess the students ability to report (#4) and to a certain extent to observe (#2) and to investigate (#3). In contrast, the students ability to properly use the laboratory equipment (#1, #5 and #6) are hidden in the description of procedures transcribed in the laboratory report. This limitation is exacerbated when students work in pairs on their laboratory experiment. One of the students in the pair is often more assertive than the other student. He or she rapidly takes the active role and does most of the manipulations. The other student's role is reduced to writing down procedures and measured values. The description of experimental procedures may be identical in the laboratory reports of the two students. Clearly, the active student will have learned much more from the laboratory experience than the passive student.

Paper-and-pencil examinations have been used for assessment of student performance in laboratory classes[2]. While written tests can to a certain extent recreate experimental situations and results encountered in the laboratory, the tests limit the range of manipulation that a student can undertake to contrived situations predetermined by the test designer. Hofstein and Lunetta[1] in their review on the role of laboratories in science teaching reported the work of Kruglak who asserted that certain psychomotor laboratory skills cannot be measured with written tests. These authors suggested that assessment of laboratory skills with practical examinations should be attempted by laboratory instructors and sought by program evaluators.

Medical educators have actively investigated the assessment of performance on clinical skills of prospective physicians[3, 4.] They developed the objective-structured clinical exam or OSCE. The OSCE format is now considered the most effective instrument for assessing the students ability to gather information by manipulation and observation, process the information, and take decisions based on this information[3]. A practical laboratory exam with OSCE format has been described for assessment of high-school students performance in a biology laboratory[5]. I describe in this communication an experiment in which an objective structured exam was developed and implemented to assess the performance on laboratory skills of Biomedical Engineering students enrolled in a biomedical electronics laboratory course.

Methods

"Medical Electronics" (BME 302L) is a one semester (15 weeks) course in the Biomedical Engineering curriculum at the University of Southern California. The course is organized in two lecture/discussion periods lasting 90 min and one 3-hr long laboratory per week. The course material covers basic analog electronic devices (transducers, diodes, transistors, operational amplifiers) and electronic functions (dc supply, amplification, filtering, waveform generation) commonly found in medical instrumentation. Examples discussed in class and portions of the laboratory experiments expose the participants to applications related to medical instruments.

Thirty to 40 junior and senior undergraduates in Biomedical Engineering at the University of Southern California enroll every year in this required course. Prior to enrolling in BME 302L, the students have taken a linear circuits course that has a laboratory component. The students have also had laboratory experiences in chemistry, physics, and biology courses. Assessment procedures in some of these courses include pencil-and-paper laboratory tests but for the most part, the students have never participated in a practical laboratory exam during their college studies prior to enrolling in BME 302L.

Students in BME 302L work in pairs to complete nine laboratory experiments during the semester. The laboratories have a traditional format in which students follow procedures outlined in the laboratory handout to assemble electronic circuits and take measurements on the circuits. The last four weeks of the semester are spent completing a laboratory project in which the students design and implement a biomedical device prototype (electrocardiograph, electrooculograph, oximeter front-end, etc.).

Two weeks before the laboratory exam, I review the assigned readings, the class notes and the laboratory handouts. Important skills and practical knowledge that the students should have acquired by studying the course material and working through the laboratory experiments are identified. A review sheet is prepared with this list of skills and knowledge[5]. The list is discussed in class to allow the students to understand what is expected of them in the laboratory exam. The format of the exam is also discussed with the students. Sample items from the review sheet are presented in table 1.

Expected skills for the lab test: To pass the test successfully, you should be able to:

- Use the "measure" and "cursor" functions of the oscilloscope to read amplitude, period, and frequency of a waveform;
- Test diodes and transistors with an ohmmeter;
- Measure the voltage-current characteristic of a zener diode and estimate the zener voltage and the zener resistance;
- Measure the ac voltage at the input and output of a common-emitter and common-collector amplifier; use the measurement to determine experimentally the unloaded gain and the loaded gain of the amplifier;
- Measure the frequency response of a high-pass or a low-pass filter and determine the critical frequency of the filter;

Table 1: sample review items for the objective structured laboratory exam

The objective structured laboratory exam comprises six test stations each developed to test the students performance mainly on one of the skills identified on the review sheet. Basic skills of the electronics laboratory are required at most stations. Students find at each test station an electronic circuit assembled on a protoboard and cables to connect the circuit to a power supply and to benchtop instruments (oscilloscope, digital multimeter, waveform generation). A sheet of instructions specifies the measurements or tests that the students must perform at the station. Students have 10 min to complete the experiment after which they are asked to return the circuit to its original state. The students turn in their answer sheet and rotate to the next test station. The laboratory exam is completed in about 1 hour 15 min taking into account the time for initial instructions and the time to rotate between stations. The instructor and one teaching assistant are present in the laboratory room at all times during the examination.

One of the stations (Fig. 1) assesses the students ability to test diodes with an ohmmeter (2nd skill in table 1). Four diodes are inserted in the protoboard and covered with masking tape (Fig. 1, left) such that the students do not see the cathode band. Students are instructed to test the diodes and determine if they are working or defective. For working diodes, they must determine if the anode faces the top or the bottom of the protoboard. For defective diodes, they must determine if the diode is open or shorted. In the actual setup, (Fig. 1, right) three diodes are working and one diode (D3) is shorted. To successfully complete the task, students must recall that a working diode has high resistance in one direction and low resistance in the opposite direction. In addition, they must analyze the ohmmeter output to associate a low resistance with having placed the positive lead of the ohmmeter at the diode anode and the negative lead at the cathode. In practice, I have observed that whereas students usually master the recall aspect of this task, several of them incorrectly interpret the resistance readings. In this sense, they do not display the higher-order reasoning skill required to complete the task. Eight answers are requested at the station and students earn 1/8 of the points for each correct answer.

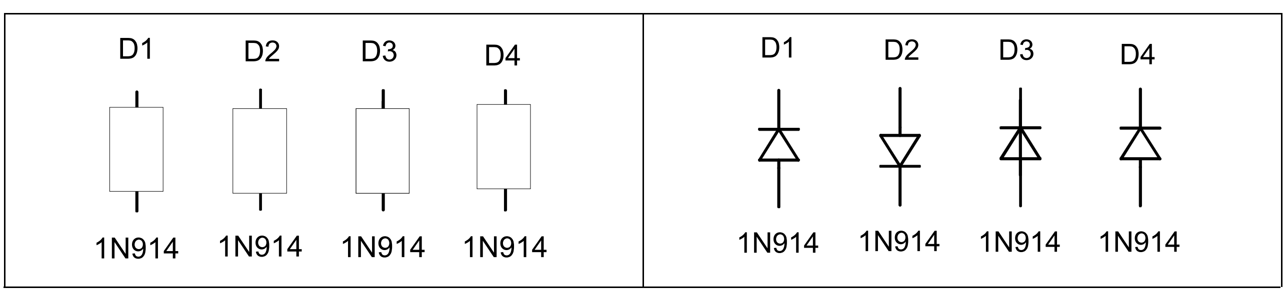

Figure 1: Diode test station. Left: diodes covered with tape; right: diodes uncovered

Another station (Fig. 2) tests the students ability to analyze a transistor amplifier circuit and to determine the loaded gain and the unloaded gain of the amplifier (4th skill in table 1). For successful performance on this task, students must understand the functioning of the common-emitter amplifier and recognize the transistor bias circuit and the 1 kΩ load. They must reason that the load resistor should be disconnected from the transistor collector to determine the unloaded gain. In addition, several basic laboratory skills are required to complete the task. Students must be able to relate the circuit schematic to the actual circuit on the protoboard. They must be able to set the waveform generator and to read voltages and frequencies with the oscilloscope. In practice, I have observed that a number of students do not think about disconnecting the load or they disconnect the wrong resistor when trying to measured the unloaded output voltage. Some students waste considerable time to measure correctly the ac voltages at the input and the output because they are at first misled by the dc bias at the base and the collector of the transistor. This particular problem was more acute before our laboratory rooms became equipped with oscilloscopes with an "autoset" feature. Objective scoring at this test station is obtained by imposing that credit is given when the students answers are within ± 20% of the values found when the circuit is tested before beginning the examination.

The circuit on this station is a common-emitter represented on the schematic on the right. The input of the circuit is marked with a short purple wire sticking out of the protoboard. Your task is to determine the loaded gain and the unloaded gain of the amplifier. You will need to alter the circuit for one of these measurements.

1. *Attach the necessary power, ground and measurement leads. Power up the circuit.*
2. *Connect the waveform* generator *to the input of the circuit. Adjust the amplitude and frequency of the input to 200 mV and 2 kHz.*
3. *Read on the scope the amplitude of the base voltage and enter the value here: _____*
4. *Enter the loaded gain of the circuit here: _____*
5. *Enter the unloaded gain here:_____*
6. *Return the circuit to its original state.*

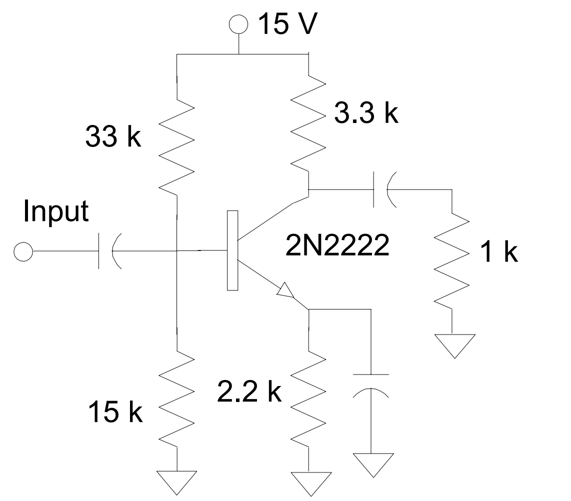

Figure 2: transistor amplifier test station; student instructions and circuit schematic

The other four stations of the laboratory exam use the following circuits:

- A dc transistor circuit on which students determine the transistor operating point and the dc load line;
- A zener diode circuit used to find the zener voltage and the zener resistance;
- An non-inverting amplifier built with an operational amplifier on which the students determine the amplifier gain;
- A four pole active filter circuit for which the students must determine if it is a low-pass or a high-pass filter and find the filter cutoff frequency.

Note that the protoboards at the test stations have two identical circuits. If a student damages one of the components in a circuit, the teaching assistant or I help the student rapidly switch to the other circuit to continue with the tasks required at the station.

Results and Discussion

The objective structured laboratory exam was tested during the 1996-97 academic year and implemented in its present form during the 1997-98 and 1998-99 academic years. Figure 3 shows the laboratory exam scores as a function of the students average score in three inclass exams (two midterms and one comprehensive final). The inclass exam scores explain only a small fraction of the variance of the laboratory exam scores ($R^2 = 0.37$). By comparison, the fraction of variance of the score on the final exam explained by the average of the scores on the two midterms is $R^2 = 0.65$. This observation is explained by the fact that the preparation and problem solving skills required for good performance on pencil-and-paper exercises during the inclass exams are different from the laboratory performance skills measured by the structured laboratory exam. For instance, the data points marked by arrows in Fig. 3 correspond to students whom I had identified as being competent during the laboratories but who consistently obtained low scores in exams presumably because of low effort. Low levels of correlation between laboratory practical exams and written tests have observed in other studies.[1]

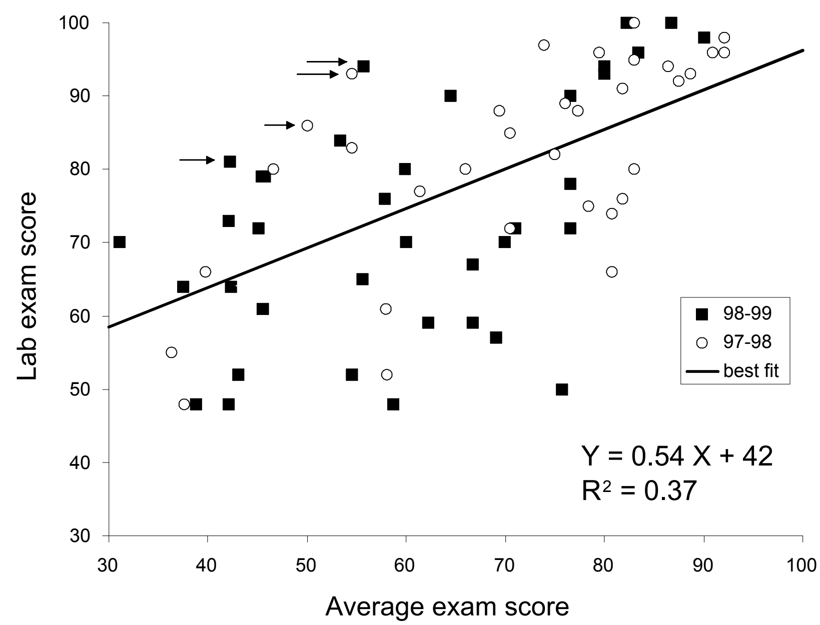

Figure 3: Lab exam score as a function of average inclass exam score

The reliability of the laboratory exam estimated by Cronbach's alpha was average: 0.62. The reliability could be improved by increasing the number of test stations. OSCE exams in the medical field have been found to be reliable when 8-18 stations are used (J. Nyquist, personal communication). A more reliable exam could easily be obtained simply by doubling the number of stations and administering the exam to 12 students at a time.

A number of benefits have been identified to the use of the structured laboratory exam for assessment of students in BME 302L. First, the laboratory exam allows the instructor to better understand the skills that students retain from the laboratory experience. One can assess the extent to which certain laboratory skills that are considered important have been mastered by the students. If too few students are found to master a certain skill at the time of the laboratory exam, the laboratory experience can be redesigned to change the exposure the students get to that particular skill.

Second, the students know that they will be tested on their laboratory performance skills at the end of the semester. Therefore, they seem to be more active participants in the laboratories. They understand that processing the experimental data they gathered in the laboratory to prepare a report is not the only important part of the laboratory experience. What they actually do during the laboratory experiment is also important. They know that mastery of certain laboratory psychomotor and reasoning skills is expected of them for successful completion of the course.

Third, inclusion of the laboratory exam in the grading scheme increases the amount of credit points associated with the laboratory part of the course. Students sometimes complain that the laboratory work requires as much if not more time than studying the course material and doing homework but yet counts for little in the course grade. With the laboratory exam, the assessment of class performance is more balanced between work in the laboratory and problem-solving work.

The time required to prepare and administer the laboratory exam is its most important limitation. For an average class size of 35 in BME 302L, the teaching assistant and I spent about eight hours in the laboratory just to set up the stations and administer the exam. During the exam, we must be on the lookout to spot students who stop because one circuit component was inadvertently damaged. Such instances must be identified immediately to avoid having the student fail the station and having the following student arrive at a station that is malfunctioning.

With the present format, the manipulations that a student does at a station affect the state in which the student that follows finds the station. This may be an advantage because for instance the second student at a station finds the laboratory instruments with correct settings that were adjusted by the first student at the station. Since all students are first at one of the stations, this effect averages out.

In conclusion, I have found that developing and implementing the objective structured laboratory exam was a worthwhile learning experience that has benefited the Medical Electronics laboratory course in our Biomedical Engineering curriculum. Observation of the students performance in the laboratory exam has allowed me to obtain useful feedback of what the students learn in the laboratories. This feedback information can then be analyzed to improve the design of the laboratory experience the students gain in the course.

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