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LAB EXAMINATIONS IN "ENGINEERING MEASUREMENTS": MORE THAN TEN YEARS OF EXPERIENCES

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The undergraduate programs in "Electrical Engineering" and "Automation and Mechatronics" include a course in engineering measurements. The resources are focused on laboratory exercises. As a consequence laboratory examinations have been developed. Today it is a much appreciated examination method among the students and it is used routinely. The logistics have been tuned so that the extra work needed is of the size that it is sustained in the regular course budget. This paper describes how the lab examination method has developed from the first small pedagogical project to be a natural part of the courses.

Keywords: laboratory examination, engineering measurements

INTRODUCTION

In 1995 there were slightly more than 200 students in the first year course in ``Electrical Measurement Techniques''. There were 18 laboratory exercises, each one four hours long. In total, more than 1800 hours per year were spent by supervisors in the lab compared to about 70 scheduled hours per year of lectures and problem solving exercises. Furthermore, resources were spent on investments and maintenance of the laboratory instruments.

Although most of the resources were spent on the lab activities, the motivation of the students was not aligned with the goals of the course. The pedagogical problem could be traced to the classical statement that the examination is the *de facto* course plan. This is one component out of many in the so called *"Hidden Curriculum"* (Snyder 1972). We assumed that if the examination could be made more relevant to the actual laboratory work, that would increase the motivation of the students, and would help in order to reach the goals of learning. These goals have been reformulated a few times over the years. Today's formulation of the relevant goals are contained in the following learning outcomes:

After completion of this course, the student should be able to:

- present an overall understanding on the use of measurements in order to obtain basic data for decision-making including applications in environmental monitoring,
- perform measurements described by electric circuit diagrams using digital multimeters, oscilloscopes, and time and frequency counters,
- use constructive as well as critical behaviour in order to assess limitations and uncertainties in a complete measurement system often with a starting point in the data sheets and specifications from the instrument manufacturers.

In this paper I will first describe how the lab examination method has developed from the first small pedagogical project, to be a natural part of the courses. I will focus on the course given in the Electrical Engineering programme, since this is where it started, but note that the development in the parallel course for the Automation and Mechatronics programme has been similar. Thereafter, I will describe the type of examination problems used and reflect on the type of knowledge that can be tested. I will discuss some overall consequences and what the activities have meant in terms of gender issues. The conclusions end the paper.

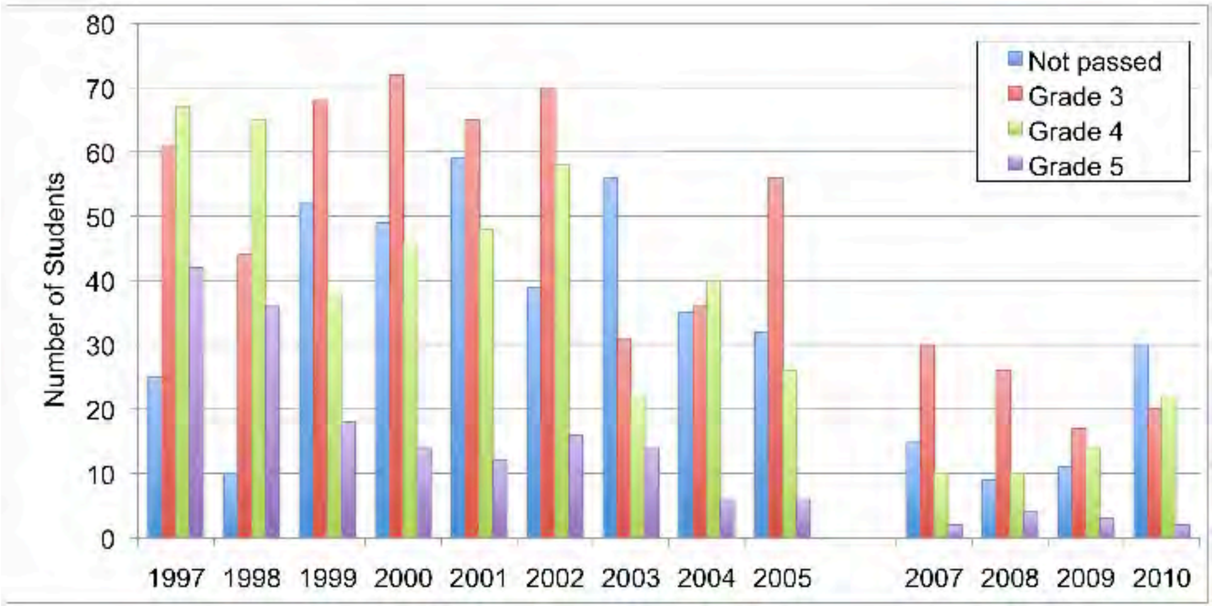

Fig.1. Lab examination results are shown in terms of the accomplished grades. The striking feature of the histogram is the dramatic decrease in the number of students over the time period. In order to relate to the grades given, one can note that of all grades, for passing, for all courses at Chalmers during 2000–2009, there were, 42.15%, 37.45%, and 20.40% of the grades three, four, and five, respectively.

DEVELOPMENT FROM 1996 TO TODAY

Given the arguments above, a coffee room meeting in early 1996 resulted in a decision that the examination somehow should be focused on the lab activities. However, in spite of our conviction we hesitated because of the anticipated logistics involved. In summary, the examination of the course in the Electrical Engineering programme has developed from continuous discussions between teachers and students, trying to find the balance between: (1) an examination which tests the relevant issues (see the goals above), (2) keeping the course budget within its required limits, and (3) having a fair assessment where not only collaboration skills but also the quality of each individual is graded. I have learned that this final point is often a very sensitive issue for the student. Perhaps this is a heritage from the many years of assessments that have been carried out in his/her school career? Here follows a summary of the development of the examination used over the years:

- A pedagogical project, carried out in the spring semester of 1996, offered a lab exam as a voluntary alternative for 24 students—from a total 165 students. The exam consisted of two measurement problems and 6 theoretical problems. All were solved on an individual basis. Since there were only 8 lab benches the exam had to be given three times during one day. In the course evaluation 23 of the 24 students, and all the teachers involved, expressed their strong support for a continued development of this examination method.
- In 1997 it was time for a full-scale experiment. Fortunately the lab was now physically extended and provided room for twelve lab benches, with their own instrumentation. The exam was divided into two parts, first a measurement part where two students worked together on two practical measurement tasks. When they felt done with the measurements, the results were handed in, in written form, and they then carried out an individual second part which consisted of a classic exam with six problem solving questions. The same procedure was adopted in 1998.

- In 1999 there was time for a change. The reason was that the relatively short individual problem solving questions had become predictable. Although they were selected to cover the central parts of the course content the limited time available stipulated that the questions could not require long answers. In spite of the good results (see Fig. 1), a significant number of the students argued that there was too little time in order to carry out and report the measurements. From now on the examination had three measurement problems that were to be solved by groups of two. The entire four hours of the exam were hence available to carry out and document the measurements. The cost of this improvement was the fairness, in the sense that the students were not assessed on an individual basis.
- The number of students kept decreasing, from approximately 180, in 1999, to 50 in 2008. In the course evaluation of 2008, the fairness question about having exams in groups of two was raised. Compared to the situation ten years ago the number of students in the course was less than half. Although the budget had been correspondingly reduced, it was not totally unrealistic to introduce individual lab exams. From 2009, the exam has consisted of three measurement problems to be solved and reported in written form individually.

EXAMINATION PROBLEMS: WHAT IS TESTED?

Referring to the course goals, the examination problems shall require: (1) a systematic approach to a specified measurement task, (2) an optimum measurement method, (3) the proper use of instruments, and (4) a critical assessment of the result. One advantage of the lab exam is that all these issues can be addressed in a more natural way, compared to a classical written examination. The lab exam problems used can be divided into four different categories:

- Black boxes: a two (or four-) terminal component is handed out and the measurement task is to determine the characteristics of the component (see Fig. 2). It could be a simple capacitor, or an inductor in series, or in parallel, with a resistor.
- Secret signals: in the lab we have a signal distribution network that is used to supply each lab bench with signals. Using an arbitrary function generator we simulate signals from different types of sensors. The task can be to determine one, or many, signal parameters. These can in turn be related using a model, described by an equation given with the examination text, to a final parameter to be inferred, with its uncertainty arising from both uncertainties in the measurements as well as from uncertainties in the model parameters.
- Design tasks: using components available at the lab bench the task can be to design, connect and verify a specific function. For example, we may ask for the design of a low-pass filter with a specific cut-off frequency. The measurement task may be to verify the cut-off frequency and to measure the phase difference between the output and input signals.
- Assessments of instrument specifications: based on the data sheets (which are available during the exam) the measurement task may be to verify a certain parameter in the specification, e.g., the root-mean-square (RMS) output voltage of a signal generator, or the rise and fall times of the pulses from a square-wave generator.

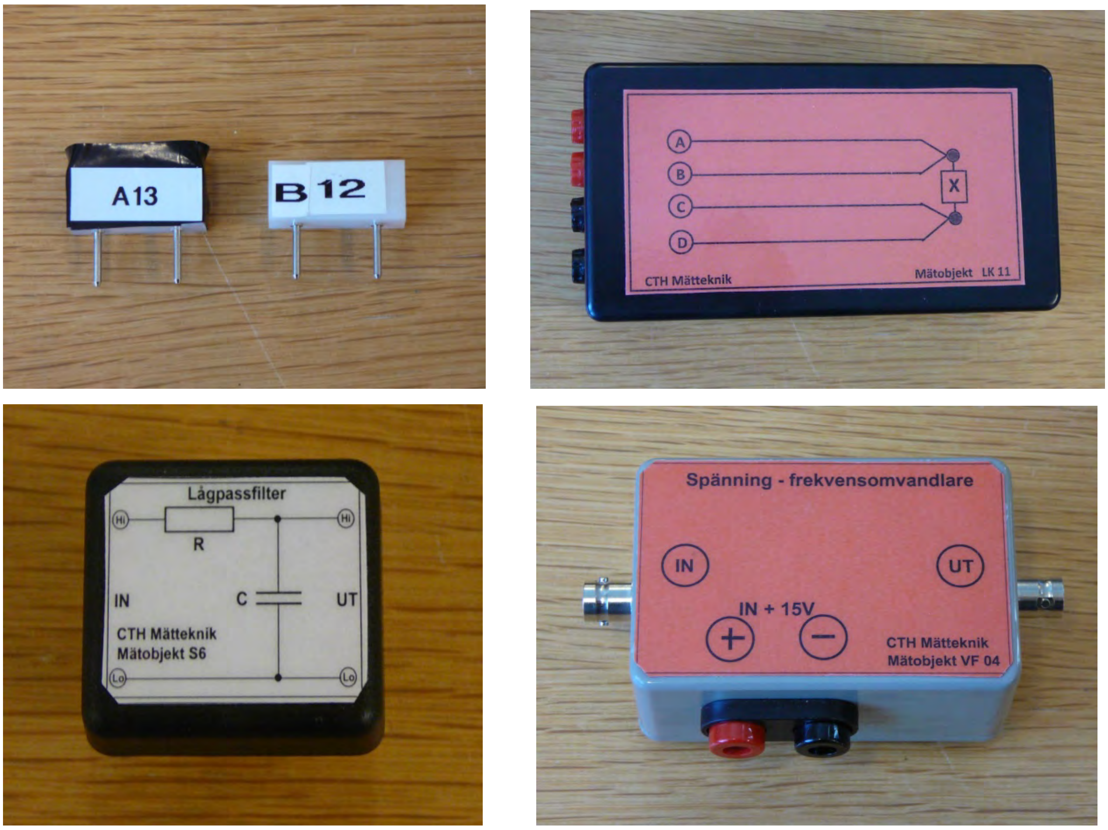

Fig.2. Measurement objects used in lab exams: (top, left) two-terminal components consisting of e.g. a resistor, capacitor, inductor, diode, or any combination of these, (top, right) a two-terminal component connected by four wires in order to measure low resistor values, (bottom, left) a low-pass RC-filter of 1st order, (bottom, right) a voltage-to-frequency converter.

Using Bloom's taxonomy (Bloom 1956; Pohl 2000) we can use the verbs describing the levels of knowledge that can be tested: remembering — understanding — applying — analyzing — evaluating — creating. All of the above measurement problems can relatively easily address the first four levels. In order to evaluate, we can offer two different methods to solve a measurement task, where one is superior in terms of the uncertainty of the final measured value. In order to create, a large degree of uniqueness is often required. I find that it is difficult to produce new and unique exam questions continuously, which is really required in an environment with mass education and mass examination. Nevertheless, it does happen that a student hands in a solution to a problem, which was not addressed during the course itself, nor predicted by the examiner formulating the text and the guidelines for marking the exam question.

When marking the exams, the typical issues assessed are:

- Has the problem, as formulated in the exam text, been understood, i.e., is there a documented description on the strategy for the measurements?
- Is there a circuit diagram? Is it correct?
- Are the measurements correct and according to the plan and the circuit diagram?
- Are the different error sources identified and valued relative each other (from instrument specifications and given formulas with uncertain parameters)?
- Has the best method (lowest uncertainty of the measurement result) been used?

DISCUSSION

In order to fulfil the above listed requirements, a certain degree of an overall understanding is needed. Again referring to Bloom's taxonomy I argue that it is very difficult to memorize how a measurement problem is solved, in order to obtain the highest score, especially since the degrees of freedom when choosing a problem offers an almost indefinite number of "black boxes" and "secret signals". Could it be that this examination method actually addresses the higher levels of knowledge in Bloom's taxonomy compared to the much more common written exams, and that this is reflected by the relatively low number of top grades compared to the average course at Chalmers (see Fig. 1)?

In more general terms it has been shown that memory retention is improved by laboratory work. Bryant, Gieskes & McGrann (2009) concluded that both interactive programs and hands-on execution gave improved examination scores compared to demonstration activities. Given that we include a large amount of laboratory work in our courses in engineering measurements, I think that it is important that this is also reflected in the examination method. Felder & Silverman (1988) discuss the importance of learning and teaching styles in engineering education. In our courses the aim is to have a coherent teaching style, throughout the course, that would stimulate a similar learning style, both in class as well as out of class. Gibbs & Simpson (2004) have written an article *"on how to design assessment that supports worthwhile learning"*. Here they discuss, e.g., the advantages of coursework compared to examinations. I argue that laboratory work is a type of coursework, although in our case it ends with an examination. They also discuss the difficulty to motivate the students to actively receive feedback during a course. In our case I think that the fact that the students know that the examination will take place in the measurement lab, actually is a reason for them not only to read feedback, given during lectures or via the home page of course, but also actively request comments about their performance from the lab supervisors during the course.

There are some other issues of interest in the context of lab exams. The work for the teachers is significantly larger compared to a classical exam. In terms of job satisfaction this is however balanced by the extra attention received during the entire course, and especially as supervisor in the lab, when the students are highly motivated to understand and apply the new knowledge. The acceptance among the students for the lab examination is generally at a high level. We also note that one of the learning goals in the course, to use a critical behaviour and assess the uncertainty of a measurement result, becomes a natural part of the examination.

There is (or at least was) a gender issue related to the lab exam method. The following comment was received from a female student in 2001: "*Lab examinations are not fair to women, several of my male friends have oscilloscopes at home, but none of my female friends* ... ".

Such a statement may be challenged in different ways, but there was also other evidence indicating that a gender issue existed. Female students were over-represented during a rehearsal class just before a re-examination event in that year. These facts trigged a gender project that was carried out during the autumn semester of 2001 (Rinaldo 2002). In short, one lab group of 18 female students, plus a female supervisor, were practicing the method of Supplemental Instructions (SI), see e.g. Malm, Bryngfors & Mörner (2010) during the course. It is difficult to draw any conclusions from this project, but it can be noted that the examination results of the SI group were comparable to all other groups, and superior to the results of the female students that did not choose to participate in the SI group. One interpretation of this result is that we are mainly seeing a systematic selection effect—the motivation may have been higher among the female students that volunteered for the SI group. Perhaps the situation today is slightly different. Neither boys, nor girls, seem to use oscilloscopes at home. In any case, the examination results during the last couple of years have not revealed any large systematic difference between the grades of male and female students. Presently the larger concern should be the imbalance in terms of the number of students that apply to these engineering programmes. Male students are over-represented by a factor of roughly ten. Today we discuss the usefulness of carrying out this type of activities focusing on a minority. It is been shown that it may result in a negative stereotyping and that the group that was supposed to be encouraged instead experiences a problem to identify themselves with the school, or learning environment, resulting in a poorer learning outcome (Steele 1997).

CONCLUSIONS

It is clear that laboratory examination as the major assessment is widely accepted among colleagues and students. The response to the general question in each year's course evaluation form "What is your overall impression of the course?" has on the average increased, from significantly below 3 in 1995, to significantly above 4 in 2010 (on a scale from 1 to 5). In fact, we have painted ourselves into a corner. The few times that I have raised the possibility of replacing the lab exams with other activities I hear protests. The focus of course development for the next few years shall be on the improvement of the lab exercises themselves, together with the development of new examination problems that stimulate the creativity of the students—simply because last year's exams are the most relevant study material for this year's exams.

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