Evaluation Tools for a Microelectronics Remote Laboratory

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Abstract

Remote laboratories have become increasingly popular in engineering education, gradually replacing traditional hands-on labs. However, in the specialized field of microelectronics fabrication the move towards remote labs has been slow. This is due to the nature of the fabrication facilities, the cost and the extra challenges involved in such transformation. There has been wide debate regarding the effectiveness of remote labs in general and whether they can truly replace traditional hands-on laboratories. At the School of Electrical and Information Engineering, we are testing the effectiveness of a newly-designed and built remote laboratory in Microelectronics. In this paper we present the research tools used to determine the effectiveness of such e-learning tool and compare learning outcomes of students using the remote version of the lab and of those using the traditional laboratory. We discuss the learning objectives of the laboratory and the manner in which they have been derived from the students' written reports. The outcomes of this trial could influence the implementation of more remote laboratories in this field. Some of the results of the first student trial are reported.

Introduction

The hands-on practical laboratory has always been a major component of many undergraduate engineering courses. It has always been the main, and sometimes only, source of hands-on experience for the undergraduate students.

With the globalization of education, more course material is being made available online. In the past, this material consisted of lecture notes, tutorial solutions etc. However, in the last decade remote laboratories have been added to the teaching tools available for students online. With this new addition there has been a wide debate concerning whether the traditional hands-on laboratories can actually be replaced with the remote alternative. The effectiveness of these remote laboratories in reaching the desired objectives of the traditional laboratory has always been the subject of a vigorous debate amongst engineering educators. In an attempt to settle this ongoing debate, researchers, in the past, have performed evaluations on these remote laboratories. These evaluations have included the measurement of student's perceived learning and the measurement of learning outcomes displayed in assessment tasks. This paper presents the tools that have been used for evaluation of the effectiveness of a remote laboratory in the field of microelectronics fabrication.

The Remote Laboratory

The remote laboratory that this paper evaluates is the Micro-Electronics Fabrication Laboratory, MEFLab. MEFLab was developed as part of a research project, at the University of South Australia (UniSA), that evaluates both the technical feasibility and teaching effectiveness of the remote laboratory in the specialised field of microelectronics fabrication. MEFLab allows users to remotely test electronic devices on a wafer such as the one shown in Figure 1. As illustrated in Figure 2, the laboratory allows users to probe different test points by manipulating micro-probes [1, 2]. The characteristic curves of the device under test can be displayed using a curve tracer which provides users with complete control over its parameters. Users can also control the bright and dark field lighting which highlights different features of the wafer. The user interface allows logged-on users to coordinate activities, thus emulating team work usually present in the traditional – proximal laboratory.

Figure 1 A typical circuit on a wafer used in MEFLab

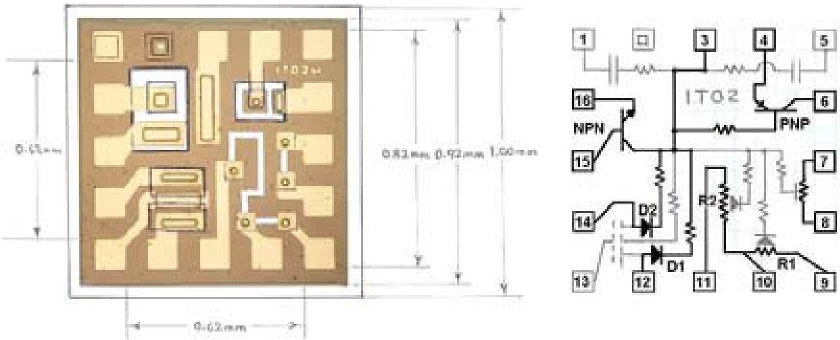
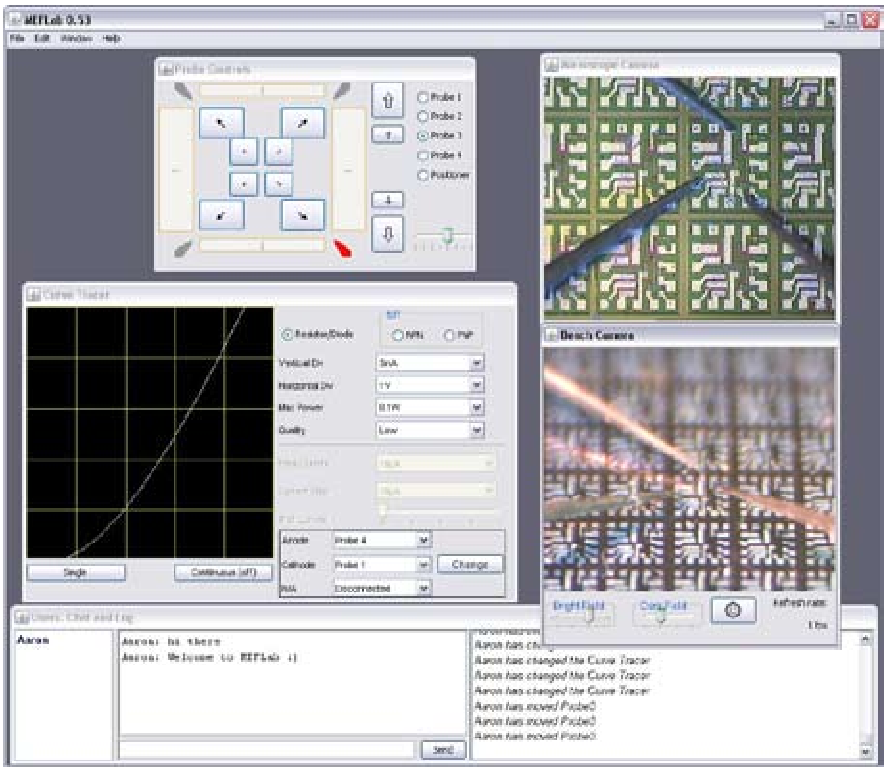


Figure 2 MEFLab's graphical user interface



As mentioned earlier, there is an ongoing debate between researchers regarding the true effectiveness of remote laboratories in engineering education. Many argue that remote laboratories cannot replace the traditional ones when it comes to achieving the learning outcomes desired from the laboratory experience. However, recently there has been an insurgence in research activities [3, 4] that attempted to provide evidence that remote laboratories can in fact enhance the student's learning experience.

The research project presented here follows this track in an attempt to evaluate the learning outcomes acquired by students. These learning outcomes are derived from behaviours that students display in their reports, which they write during and after conducting experiments in the remote and physical (proximal) laboratories. The following sections detail the research design and tools that were used to evaluate the effectiveness of MEFLab.

Research Design

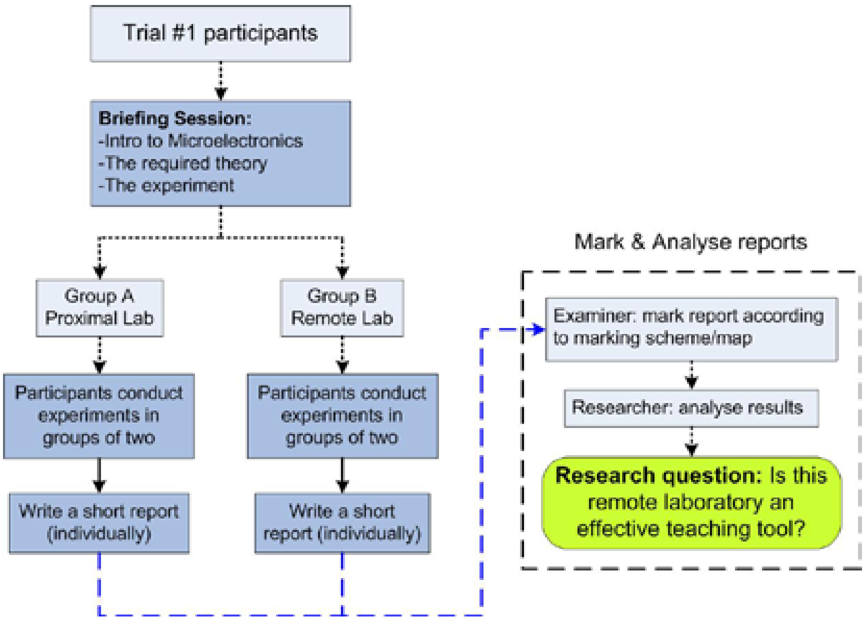
This research project attempts to measure the effectiveness of the remote laboratory MEFLab. To accomplish this, the research design involves the inclusion of students that conduct a purposely designed experiment in either the remote or the traditional – proximal access mode. After conducting the experiment in the designated laboratory, students complete a written report which captures their understanding of the relevant topics. These reports are later used to extract the behaviours displayed by the students and the subsequent learning outcomes acquired by them. The basic research design used for the first main trial is illustrated in Figure 3.

The Laboratory's Learning Objectives

Evaluating the remote laboratory involves measuring how well the learning objectives are met. These learning objectives are derived from those of the traditional laboratory. As mentioned by Scanlon et al [5] the generic learning objectives of an experimental laboratory are:

1. To illustrate and reinforce the theoretical concepts of a topic.
2. To enhance experimental skills.
3. To introduce students to the world of scientists and engineers in practice.
4. To facilitate interaction between students and the supervisor.
5. To motivate student and develop positive attitudes towards the subject.

Figure 3 The research design used in the first main trial



For the purposes of this research, the generic objectives specified above have been condensed/clustered into three main objectives that are suitable for the experiments conducted using MEFLab. These objectives are:

1. To illustrate and reinforce concepts and theories.
2. To develop skills in the use of equipment and instrumentation.
3. To understand and cope with the non-idealities in the real environment.

The main objective missing is the social one that deals with the interactions among students themselves, and with their supervisor. This objective has been purposely left out in this research due to it negative confounding effects on the statistical analysis of the results, which are discussed later.

The mentioned objectives are the desired outcomes that students, participating in the experiments, should display. To measure these outcomes, a set of behaviours relating to these outcome are measured.

Student Behaviours

The students' achieved learning outcomes are extracted from a set of behaviours that students exhibit in a written report. For the experiment that was conducted in one of the main trials, a set of desired student behaviours/abilities were identified. The main behaviours are:

- Drawing the characteristic curves with the appropriate selection of the graph scales, labeling the axes and divisions.
- Selecting the appropriate points on the graphs to extract the required data.
- Finding/calculating the parameters from the graphs.
- Listing the non-idealities that could've affected the graphs accuracy.

The presence or absence of each one of these behaviours in the student's report was measured and used to calculate the corresponding learning outcome. It is accepted that individual behaviours could contribute to more than one of the identified learning outcomes. Figure 4 illustrates the comprehensive mapping of the students behaviours to the learning outcomes used in the first main trial.

Assessing the Reports – Ensuring Objectivity

To promote and ensure objectivity, consistency and repeatability of the student reports' results, a detailed marking scheme was developed. The marking scheme for the first main trial is illustrated in Figure 5. The use of only one examiner to assess all reports was also implemented as a measure to further improve consistency. Objectivity was improved by having the sequence of the reports randomised and the marker unaware of the access mode used.

Results of the First Trial

The first main trial included 60 participants approximately, where participants were third-year engineering students, studying electrical engineering courses, but who had no prior experience in microelectronics fabrication. The participants conducted the experiments in their assigned access mode, the written reports were marked, the learning outcomes were derived and the results were analysed. The MANOVA (Multi-Variate Analysis of Variance) was used as a statistical analysis tool which compares the difference in variances of dependent variables between the two groups of samples. The independent variable was the access mode, which was either remote or proximal. The dependent variables were the three different learning outcomes that were mentioned earlier. Other factors that could influence learning outcomes and thus the results of this research were also taken into account. These factors include the participant's demographics (age, gender, study mode etc), the participant's prior knowledge and the participant's preferred learning style.

The results revealed that the access mode did not have an effect on its own, but an interactive effect with other factors. It was shown that the interaction between the access mode and the English speaking background of the participant had an effect on learning outcomes 1 and 3. Non-English speaking students performed better in both learning outcomes when conducting the experiment in the remote laboratory, while English speaking participants performed worse in the remote laboratory (Figure 6). The interaction between the access mode and international status (domestic or international) of the participant had an effect on only learning outcome 1, where international students performed better in the remote laboratory.

The students' perceptions on the remote laboratory were also captured using a separate questionnaire upon completion of the reports. It was revealed that more than half of the students preferred the use of the remote laboratory, while around 25% preferred the typical-proximal laboratory. The remaining 25% indicated that they would prefer a hybrid approach to the laboratory where both access modes were used to conduct different experiments.

Figure 4 The main trial's marking map

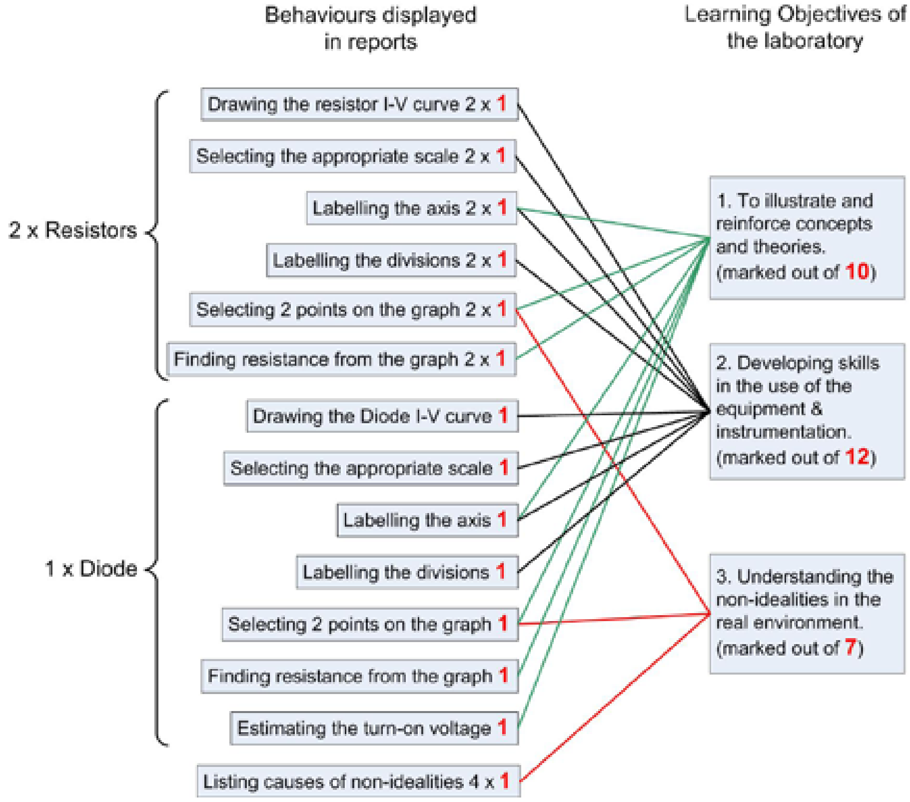


Figure 5 The main trial's marking scheme

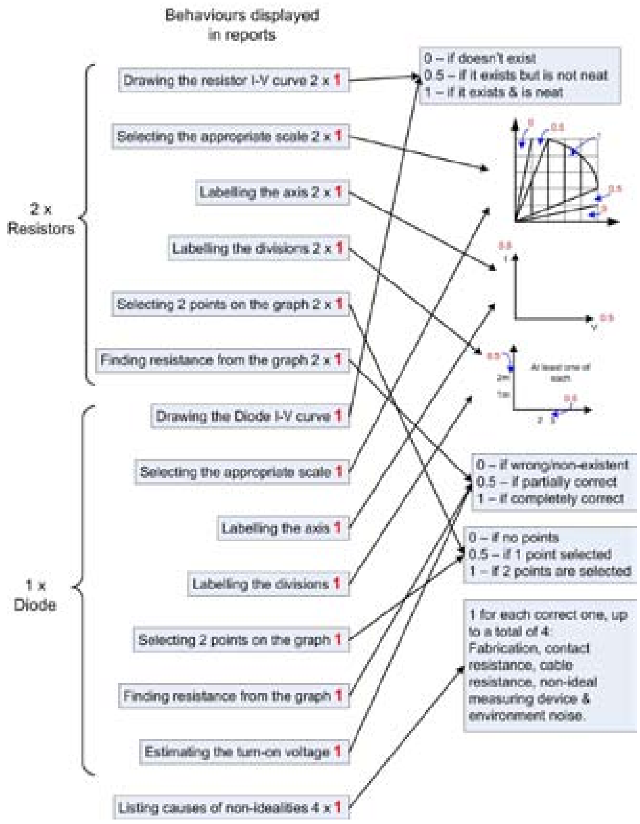
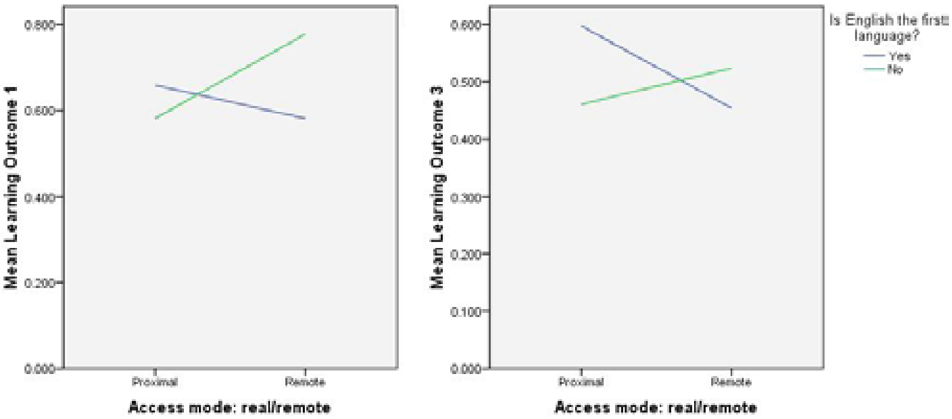


Figure 6 The interactive effects of access mode and speaking background on learning outcomes 1 & 3



Analysis of the First Trial

Although the results did not reveal any compelling – direct effect of the access mode on the learning outcomes displayed by students, this research has yielded some interesting findings. The access mode on its own had no statistically significant effect on the learning outcomes of all students, but had rather different effects depending on their international status and first language. Regardless of the degree of improvement of the achieved learning outcomes by these groups, it is clear that students from different backgrounds are able to benefit from the laboratories differently. This, coupled with the fact that many students enjoyed and preferred conducting future experiments in the remote laboratory, should encourage and provide motivation for the use of a combination of remote and proximal laboratories in microelectronics courses. This provides a wider range of teaching tools which assist students with a wider range of backgrounds and learning styles in their learning process.

Conclusion

This paper presented the research design and tools used in the evaluation of the effectiveness of a remote laboratory in the field of microelectronics fabrication. This study has measured three learning outcomes derived from behaviours that are displayed in the students' reports, which are written after conducting an experiment in one of the two laboratories. We have derived and included a summary of the results and their interpretation from the first main trial conducted. The results from this trial and the following one have demonstrably shown that implementing remote laboratories in this field can have a number of educational advantages for many students.

Acknowledgements

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