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Assessing the impact of Virtual Labs: a case study with the lab on *Advanced VLSI*

Garima Ahuja
CDE
IIIT-H
Hyderabad, India
garima.ahuja@students.iiit.ac.in

Anubha Gupta
Department of ECE
IIIT-D
Delhi, India
anubha@iiitd.ac.in

Harsh Wardhan
CVEST
IIIT-H
Hyderabad, India
harsh.wardhan@research.iiit.ac.in

Venkatesh Choppella
SERC
IIIT-H
Hyderabad, India
venkatesh.choppella@iiit.ac.in

***Abstract*—The laboratory is an indispensable component of learning in engineering education. In this paper, we examine the impact of *Advanced VLSI Virtual Lab*, which is a part of the Government of India's suite of Virtual Labs, in improving the understanding and learning of students at a small sized university in India. The Advanced VLSI Virtual Lab includes ten simulated interactive experiments in the area of design and application development. Over a hundred Virtual Labs have been proposed and built, but, so far, few have been subject to systematic investigation of their effectiveness in helping the student learn. Our work is one of the first efforts to statistically study the effectiveness of the Virtual Lab. To this end, we designed and conducted pre- and post-tests, and feedback surveys on the lab. The tests and the survey, on analysis, reveal that the lab is effective in enhancing student learning. Our results are encouraging to several teachers in India who are in the midst of using Virtual Labs at their colleges.**

I. Introduction

Engineering education and Virtual Labs: Engineering education involves teaching the fundamental concepts and design principles that go into building modern day systems that are efficient and cost effective [1]. To adequately prepare students for a career in engineering, theoretical knowledge and practical experiences are both necessary [2]. The high costs in setting up and the maintenance of engineering education laboratories make it challenging to provide laboratory facilities at institutions where budget and technical expertise are limited . In response, the Government of India has taken the initiative of setting up *Virtual Labs* [3] to address these challenges. The objective is to enable students, even in smaller colleges with poorer infrastructure, to perform experiments online. The project has so far built experiments in over a hundred subjects across nine disciplines of science and engineering.

Why study impact of Virtual Labs?: The Government of India has invested a large amount of resources on the Virtual Labs project. Yet, only a few studies have been done either to assess the demand of these labs, or the effectiveness of these labs in the occasions that they have been used[4], [5]. While the Virtual Labs are beneficial from an economic and organizational point of view, it is still being ascertained whether it has been successful in improving student learning. Such studies will form valuable strategic input into the next stage of efforts to grow the Virtual Labs.

Paper objective and roadmap: In this paper, we explore the effectiveness of the *Advanced VLSI Virtual Lab*[6]. The term "effectiveness" is defined with respect to how students perceive the Virtual Labs and how it helps them understand concepts better. The remainder of the paper is organized as follows: Section II discusses related work. Section III describes the details of the study. The analysis of the questionnaire and results of the study are discussed in Section IV. Finally, conclusions are presented in Section V.

II. Related Work

Virtual Laboratories: Virtual labs have been designed in various application domains such as thermodynamics [7], civil engineering [8], geotechnical engineering [9], and cell biology [10]. Campbell et al. (2002) studied the effectiveness of software simulations by adopting pre- and post-test design [11]. They have shown that the group that used both simulated and physical labs together performed significantly better than the group using only physical labs.

Virtual Labs: The Virtual Labs project [3] in its essence is different in its approach as it tries to bring together a content management system for course resources and a facility to virtually perform laboratory experiments. Raman et al. studied the adoption of Virtual Labs by potential engineering students [4]. Sheorey et al. (2014) carried out field surveys in order to evaluate the role of Virtual Labs in student learning [5]. However, the effectiveness of the Virtual Labs project has not been studied statistically before. It is important to assess the statistical significance of Virtual Labs in enhancing student knowledge so that the numbers can be quantitatively improved upon, which is what we have attempted in this paper.

III. Details of the Study

A. Lab Selection

The *Advanced VLSI Virtual Lab* was selected for study because the Advanced VLSI course:

- is popular amongst students,
- emphasises on laboratory experiments, and
- has high laboratory infrastructure cost.

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B. Advanced VLSI Virtual Lab

The *Advanced VLSI Virtual Lab* is designed to provide hands-on experience to students who have primarily finished three courses- Digital Logic Design and Processors, Basic Electronic Circuits, and Introduction to VLSI. The lab comprises a total of 10 experiments related to three major aspects of VLSI design: the understanding of semi- and full-custom IC design, power performance optimization, and logic circuit realization on generic architectures [6].

C. Details of the Experiment

The study was carried out at International Institute of Information Technology, Hyderabad (IIIT-H) on students of electronics engineering. Theoretical aspects were first introduced in the lecture. A quiz was then conducted to test how well the students understood the concepts taught. Care was taken that the focus of the quiz was to test the conceptual understanding and not the ability to recall details. Thereafter, students were asked to try out the *Advanced VLSI Virtual Lab*. Students were asked to conduct three laboratory experiments which were relevant to the theory taught in class. Afterwards, another quiz was conducted on the same set of students. The quizzes were carefully designed to ensure that one quiz wasn't more difficult than the other. Feedback was also collected with the post-test.

IV. Questionnaire Analysis and Results

A. Descriptive Data Analysis

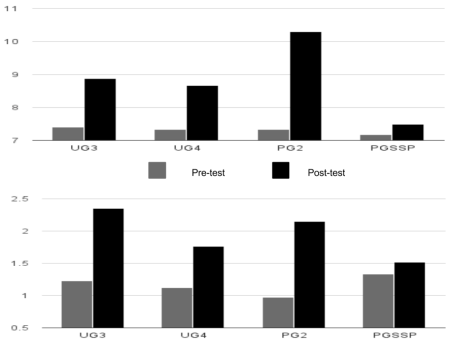

Figure 1. Top: Pre-test and post-test mean scores (out of 20). Down: Standard deviations of pre-test and post-test scores.

The student population comprised of 70 students which included third year undergraduate students (UG3), fourth year undergraduate students (UG4), second year postgraduate students (PG2), and part-time students from the post graduate student status programme (PGSSP)[1].. Out of the 70 students, 59 students took both the pre-test and the post-test. The mean and standard deviation of pre-test and post-test scores for each category of students are calculated and shown in Figure 1. From Figure 1, it can be seen that the pre-test mean score for all categories was nearly the same. While there is an improvement in the post-test mean scores across all categories, the post-test means are different. The most significant improvement is observed for PG2 and the least significant improvement is observed for PGSSP. In the next subsection, we investigate whether the differences in post-test and pre-test means as observed in the descriptive analysis are statistically significant.

[1]PGSSP (Post-Graduate Student Status Programme) is a part time programme at IIIT-H which allows professionals to take advanced courses at the institute. http://www.iiit.ac.in/academics/programmes/pgssp

Table I
Output of paired samples t-test when applied on the pre-test and the post-test scores.

t-value	df	p-value
-5.7919	85	<0.0001

B. t-test Analysis

The pre-test and post-test scores were compared using dependent samples t-test. Generally, t-tests are used to compare two groups of normal scores. Jarque-Bera test was used to ensure that the pre-test and the post-test data came from normal distributions. Also, t-tests generate different t values based on whether the groups being compared have equal variances or not. We conducted two-sample F-test with the scores and found out that they had unequal variances and we conducted the t-test accordingly.

The result of a t-test tells us whether the difference between the means of the two groups is statistically significant. It substantiates that if the test were to be applied to a larger sample, it will yield similar results. From Figure 1, it can be observed that there is an improvement in the performance of the students after performing the virtual experiments. In order to ascertain the statistical significance of that observation, we formulated a hypothesis and performed paired sample t-test to prove or disprove our hypothesis.

The null hypothesis can be stated as:

H_0: $\mu_{post} = \mu_{pre}$: the Virtual Lab didn't cause any change in students' performance.

The alternate hypothesis is:

H_1: $\mu_{post} \neq \mu_{pre}$: The Virtual Lab did cause a change in students' performance.

The result of t-test is tabulated in Table 1. From Table 1, we observe, that the test is statistically significant ($p<0.0001$) and hence, we can reject the null hypothesis. From Figure 1, we already know that the post-test scores are better than the pre-test scores and the t-test analysis suggests that the difference is significant. Thus, we can conclude that there is an improvement in students' performance with the use of the *Advanced VLSI Virtual Lab*.

Table II
ESTIMATED COEFFICIENTS OF THE LINEAR REGRESSION ANALYSIS.

Coefficient (associated with)	Estimate	Std. Error	t-stat	p-value
α_1 (Constant)	-7.8851	1.8908	-4.1703	0.00010475
α_2 (normalized course score)	0.77888	0.15059	5.172	3.1102e-06

C. Regression Analysis

Having established that the *Advanced VLSI Virtual Lab* is helping in improving students' performance, we want to dig a little deeper. We would like to investigate how the overall performance of students in the Advanced VLSI course (delivered in Fall 2013) is related to students' improvement in post-test scores of the corresponding Virtual Lab.

In order to do that, we performed a linear regression analysis with the difference between the post-test and the pre-test scores as the dependent variable, the overall performance of the students in the course as a continuous independent variable. The findings are summarized in Table 2.

From Table 2, we observe that the overall performance of a student is contributing to the difference between the post-test and the pre-test scores (α=0.78) and is statistically significant (p<0.0001). This implies that students who are good in that subject are able to make better use of the Virtual Lab. This is not surprising since one would expect such students to be spending more time experimenting with the Virtual Lab and make the best use of it.

D. Feedback Analysis

In the feedback forms students were asked to rate their opinions about various aspects of the *Advanced VLSI Virtual Lab* on a scale of one to five. Feedback survey results are summarized in Figure 2. Students have a positive response towards simulations and seem to agree that this Virtual Lab helped in improving their conceptual understanding.

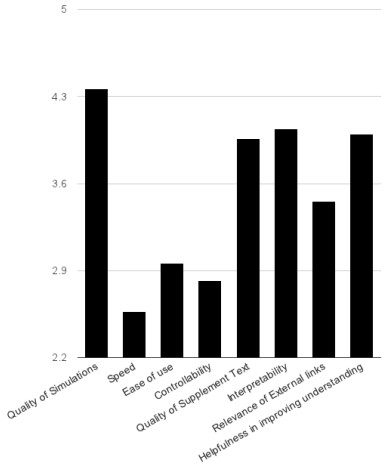

Figure 2. Feedback summarization.

V. CONCLUSIONS AND FUTURE RESEARCH

In this paper, we have attempted to assess the effectiveness of *Advanced VLSI Virtual Lab*. The results of this pilot study have been inspiring. More such studies may further strengthen our claim that Virtual Labs are indeed effective in enhancing student learning.

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