# A Survey Study of the Impact of a MIT Microelectronics Online Laboratory on Student Learning

Rudolph Mitchell[1], Judith Fischer[2], Jesus A. del Alamo[3]

**Abstract - As part of the iCampus project, MIT developed the Microelectronics WebLab, an online microelectronics device characterization laboratory that provides students the opportunity to access remotely professional microelectronics characterization equipment via the Internet. Students use WebLab to take remote measurements in order to complete assignments/projects related to current-voltage characteristics of transistors and other microelectronics devices. This paper describes a survey study of the WebLab experience of students enrolled in a junior-level microelectronics circuit and device design course that incorporated a number of WebLab assignments. Results indicate the interface was user friendly, enhanced learning, and helped reasoning. Moreover, responses suggest student learning included higher order thinking as students ran WebLab and analyzed data. They viewed the overall WebLab experience as positive, believed it should be continued, and expanded to other engineering /science classes. In conclusion, results suggest that online laboratories that are user friendly with coherent, effective interfaces provide viable learning experiences characterized by higher order thinking and in-depth understanding.**

*Index Terms* - Engineering education, evaluation, online laboratories , online learning

## Introduction

The MIT Microelectronics WebLab was created in 1998 to provide an online device characterization experience for microelectronics students (Figure 1) [1]-[4]. In this lab, students can measure the current-voltage characteristics of transistors and other microelectronics devices through the Internet (Figure 2). On the student side, a simple web browser is all that is required to access this lab. In this way, students can carry out device characterization projects from anywhere at any time. Typical assignments include device characterization, parameter extraction techniques, and model construction. To date, WebLab has been in used in several MIT courses and from overseas. Since 1998, over 2600 students in four continents have used this lab to carry out course credit bearing assignments.

This study profiles the WebLab experience of students enrolled in an electrical engineering course at MIT in which they used WebLab to complete weekly assignments [5]. In these assignments, the students were typically asked to characterize a microelectronics device, to extract some device parameters, and to compare the measured characteristics against theoretical characteristics using models presented in class. The actual lab assignments can be found in [5]. The professor also used WebLab examples in lecture to illustrate concepts and physical phenomena. Three questions shaped the study. How positive did students find the graphical interface? How deep was their thinking as they analyzed the measured data? How much do they favor the further use of online laboratories in different educational contexts and settings.

## Method

The subject is called "6.012 Microelectronics Devices and Circuits". This is a junior-level course in the Department of Electrical Engineering and Computer Science at MIT. This subject serves the role of "header" for a concentration area in microelectronics. In the Fall of 2005, this subject was attended by 68 students.

All thirty three students who attended the last

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[1] Rudolph Mitchell, Associate Director for Assessment and Evaluation, Teaching and Learning Laboratory, MIT,rudy@mit.edu
[2] Judith Fischer, Educational Consultant, Teaching and Learning Laboratory, MIT,jfisch@mit.edu
[3] Jesus A. del Alamo, Professor, Dept of Electrical Engineering and Computer Science, MIT, Alamo@mit.edu
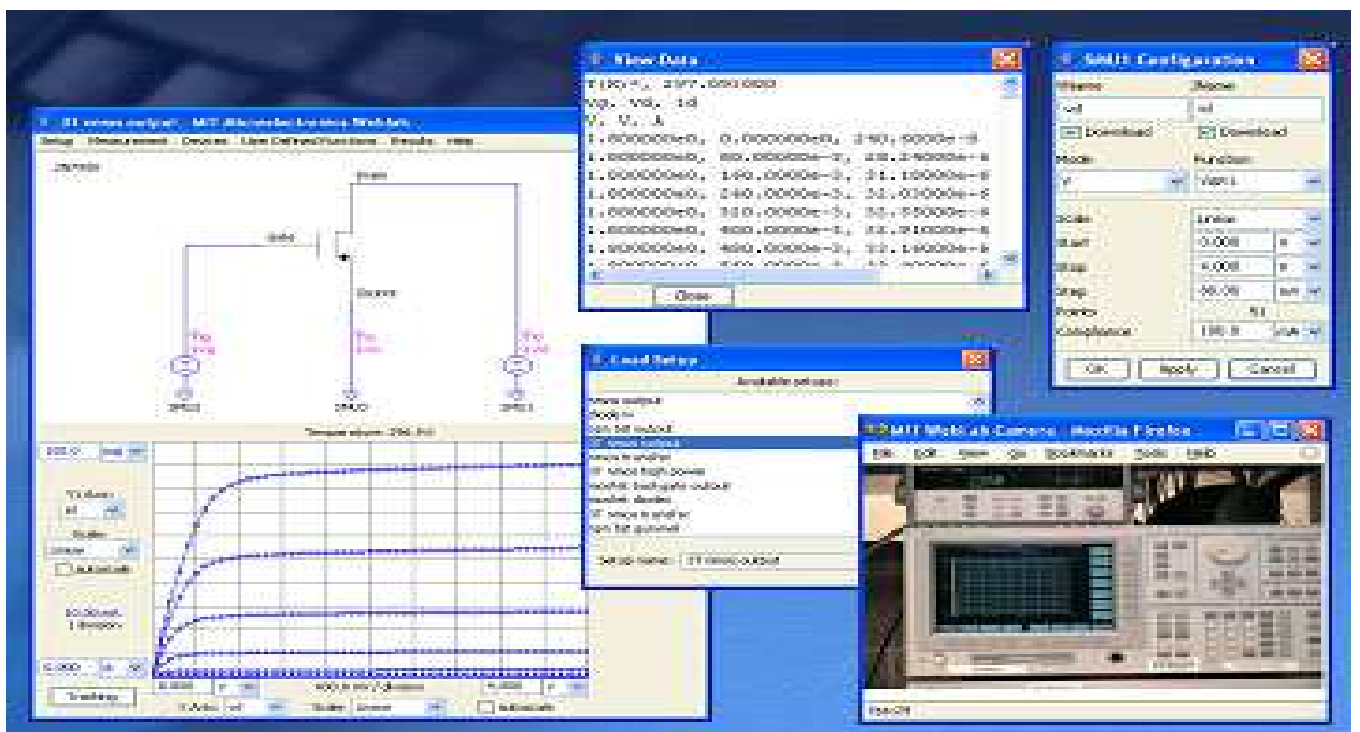
FIGURE 1
WebLab Equipment



FIGURE 2
WebLab Screen Shots

lecture completed the WebLab Survey. The survey includes 57 Likert Scale items that profile eight areas of the WebLab experience, four of which this report address: interface learning experience, learning behavior, understanding, and favorability. Students express agreement with each statement by means of seven-point rating scales; "1" indicates strong disagreement and a "7" indicates strong agreement.

Three scales were developed: interface learning experience, learning behavior, and favorability. Given that the scales were developed from the sample itself, that the number of students is small, and that factor analysis is inappropriate because the condition of a minimum subject-variable ratio of 10:1 is not met, the proposed scales are not intended to be viewed as definitive measures. Rather, the scales are viewed as exploratory tools that help profile the WebLab experience. Drawing on discussions by Streiner and Norman [5] about reliability and alternative strategies to factor analysis, the following steps were taken to construct the scales. To test the reliability of each scale, coefficient alphas and item-total correlations were calculated. Only items that correlated greater than .20 with their respective scale total were included. The reliability procedure of *SPSS 10.0 for MacIntosh* [6] statistical software was run on each scale to compute the coefficient alphas.

The interface learning experience scale consists of items which address user friendliness, the contribution of the interface to the learning experience, and presence of negative factors that would undermine the learning experience, e.g., bugs. The learning behavior scale measures the degree to which students conceptualized as they analyzed data. Conceptual learning is the cognitive process by which students acquire understanding. The learning behavior scale includes several higher order cognitive operations characteristic of conceptualization: visualizing how devices work, applying concepts discussed in lecture, or formulating concepts about the behavior of devices. Research has shown that the presence of higher order thinking in learning leads to deeper understanding [7]-[8], more elaborate cognitive representations of the subject matter [7]-[10] and stronger capacity to apply knowledge to new situations[7]-[11]. The third scale, favorability, provides a general measure of how valuable students found the WebLab experience.

The understanding section does not include a scale. It consists of five survey items that address how well students understood the relevant content.

### Results

Table I provides scale data. Coefficient alphas range from .80 to .90; all sufficiently high to provide stable measures. The three scale means are positive (above 4.00) which

suggest a positive learning experience.

Table II includes data about selected scale and related non scale items. Students viewed positively their interactions with the WebLab graphical interface as expressed by a mean of 5.32 on the Interface Learning Experience Scale. Ninety four percent of the respondents had scale means 4.00 or above, sixty four percent had scale means 5.00 or above. Students found WebLab user friendly (5.18) and the graphical interface clear and coherent (5.58). The relatively low standard deviations of 0.95 and 0.90 for the two items suggest students shared similar positive views about the user friendliness and clarity. They strongly indicated that the graphical interface enhanced learning (5.76). Only two of the 33 respondents answered negatively. Even more strongly, students reported that controlling the WebLab remotely from a PC did not interfere with their learning (6.03). It is also noteworthy that the degree to which students believed the graphical interface helped them to reason (5.45), only one student responded negatively.

The learning behavior data relate to two areas: mental operations used to gather data while running the WebLab and those used to analyze the data. As they ran WebLab to gather data, students reported thinking about the variables (5.12), reasoning about the devices (4.91), and applying concepts discussed in lecture/readings (4.82). Other cognitive operations appear to have played less of a role: visualizing (4.33), thinking about what-if scenarios (3.70), or developing working hypotheses about why some configurations worked, others didn't (4.12). Data about the mental operations used to analyze WebLab include means and standard deviations for the learning behavior scale, its items, and related non scale items. The scale mean of 4.88 indicates the presence of higher level thinking as students analyzed the data. Scale item means suggest students applied concepts discussed in lecture (5.38), formulated concepts about the behavior of the devices (4.81), and drew upon their intuition to understand the devices (4.78). To a slightly lesser degree, students visualized about how the devices worked (4.56). Several non scale items also suggest the presence of higher level thinking. Students reported thinking about relationships among variables (5.41) and thinking about how the lab experiences related to material previously learned (4.88). Other non scale items suggest that students did not think about how concepts learned from the experiments could be applied to other situations (3.72), or thought about how to integrate concepts (4.09). These last two findings may reflect the pressure of time constraints students felt in completing assignments.

Students rated positively all five understanding items. The relatively low standard deviations suggest they had similar perceptions about how well they learned. Their responses suggest that WebLab was helpful in understanding related lectures and assigned readings (4.82), behavior of devices

(5.42), developing an intuitive feel of how devices work (5.00), difference between theory and application (5.55), and how to characterize a device (5.45).

Students were favorable toward the WebLab experience as suggested by the favorability scale mean of 5.04. They found the use of WebLab examples in lecture effective (5.64), viewed the overall WebLab experience as positive (5.48), and believed it should be continued in the course (5.48) and expanded to other engineering /science classes (4.82).

TABLE I
WebLab Survey Scale Profile

| Scale | Alpha* | Mean | SD* | *n** |
|---|---|---|---|---|
| Interface  Learning Experience | .80 | 5.32 | 1.02 | 33 |
| Learning Behavior | .86 | 4.88 | 1.24 | 32 |
| Favorability | .90 | 5.04 | 1.28 | 33 |

Alpha = coefficient alpha; SD = standard deviation; *n* = number of respondents included in the calculation.

TABLE II
Likert Scale Items from WebLab Survey

| Selected Scale & Non Scale Items | Mean | SD* | *n** |
|---|---|---|---|
| Interface  Learning Experience | | | |
| * The WebLab was user friendly. | 5.18 | 0.95 | 33 |
| * The graphical interface enhanced the learning experience. | 5.76 | 1.06 | 33 |
| * I had no problems running the experiment. | 4.73 | 1.81 | 33 |
| * Controlling the WebLab remotely from a PC did not interfere with my learning. | 6.03 | 1.16 | 33 |
| *The bugs in the WebLab made the lab a frustrating experience. | 3.09 | 1.68 | 33 |
| The graphical interface presented data in a clear and coherent manner. | 5.58 | 0.90 | 33 |
| The data presentation of the graphical interface helped me to reason about the system and data. | 5.45 | 0.94 | 33 |
| Mental Operations Used To Gather Data While Running WebLab | | | |
| Visualizing how devices work. | 4.33 | 1.27 | 33 |
| Reasoning about the behavior of devices. | 4.91 | 1.28 | 33 |
| Applying concepts discussed in lecture or readings. | 4.82 | 1.38 | 33 |
| Thinking about relationships among the variables. | 5.12 | 1.34 | 33 |
| Thinking about various "what-if" scenarios. | 3.70 | 1.29 | 33 |
| Developing working hypotheses about why some configurations worked, and others didn't. | 4.12 | 1.58 | 33 |
| Learning Behavior: Mental Operations Used To Complete Data Analysis | | | |
| * Visualizing how devices work. | 4.56 | 1.56 | 32 |
| * Applying concepts discussed in lecture or readings. | 5.38 | 1.45 | 32 |
| * Using intuition to understand devices. | 4.78 | 1.52 | 32 |
| *Formulating concepts about the behavior of devices. | 4.81 | 1.38 | 32 |

TABLE II (con't)
Likert Scale Items from WebLab Survey

| Selected Scale & Non Scale Items | Mean | SD* | n* |
|---|---|---|---|
| **Learning Behavior: Mental Operations Used To Complete Data Analysis** | | | |
| Thinking about how the lab experiences relate to material previously learned. | 4.88 | 1.34 | 32 |
| Thinking about how concepts learned from the experiments could be applied to other situations. | 3.72 | 1.11 | 32 |
| Integrating different concepts. | 4.09 | 1.42 | 32 |
| Thinking about relationships among variables. | 5.41 | 1.32 | 32 |
| **Understanding** | | | |
| Related lectures and assigned readings. | 4.82 | 0.88 | 33 |
| Behavior of devices. | 5.42 | 1.17 | 33 |
| Developing an intuitive feel of how devices work. | 5.00 | 1.20 | 33 |
| Difference between theory and application. | 5.55 | 1.03 | 33 |
| How to characterize a device. | 5.45 | 1.15 | 33 |
| **Favorability** | | | |
| * Overall, the WebLab was a positive learning experience. | 5.48 | 1.15 | 33 |
| * WebLab activities should continue to be included in 6.012 | 5.48 | 1.37 | 33 |
| * I found WebLab to be an integral part of the 6.012 learning experience. | 4.42 | 1.68 | 33 |
| * Including WebLab examples in lecture was effective. | 5.64 | 1.34 | 33 |
| * I think that WebLabs ought to be used in more engineering/science classes. | 4.82 | 1.86 | 33 |
| * I think that WebLabs ought to be used in lab-type subjects. | 4.36 | 1.92 | 33 |

* = scale item; SD = standard deviation; $n$ = number of respondents included in the calculation.

## Discussion

Overall, students responded positively to the WebLab experience. Scale means for graphical interface, learning behavior, and favorability are positive. When specific items of the three scales are examined, a profile of learning emerges that reflects the strength of WebLab as a learning tool.

The graphical interface data indicate how the interface was effective in creating positive learning experiences. Students reported they found the interface user friendly, presenting data clearly and coherently. Their responses suggest that the quality of the interface stimulated higher order thinking; that the graphical interface enhanced the learning experience and helped them to reason about the data. Students also responded strongly that accessing the equipment remotely did not interfere with student learning.

The hypothesis that the WebLab experience provides the opportunity for higher order thinking is further supported by the cognitive behavior data. The data indicate the presence of higher order thinking as students ran WebLab and analyzed the data. As they ran WebLab, they thought about relationships among variables, applied concepts presented in lecture, and reasoned about the behavior of devices. As they analyzed data, they formulated concepts, visualized how devices worked, used their intuition to understand the behavior of devices, and thought about how the WebLab experiences related to material previously learned.

Given the presence of higher order thinking in the WebLab experience, student responses should reflect an understanding of the content. This is the case. Student responses suggest that WebLab experiences enabled them to understand the behavior of devices, difference between theory and application, how to characterize a device, and related lectures and readings. In addition, their responses suggest WebLab helped them to develop an intuitive feel of how devices work. That WebLab helped students to develop an intuitive feel is significant given that students accessed the equipment remotely. It suggests that without direct experience, students are able to think deeply in intuitive ways about devices. These findings are not only encouraging about ways in which WebLab may impact on learning, but they suggest an interesting line of research: the effect on intuition about devices and physical phenomena that students explore by running experiments remotely.

Students responded favorably toward the WebLab

experience. The favorability scale mean of 5.04 suggests they view WebLab as providing them with viable experiences. They view the experience as positive, effective, and an integral part of their learning. They believe WebLabs should continue as part of the course and included in other engineering and science classes.

The study goes beyond profiling the effectiveness of WebLab; it offers preliminary data on the potential of online laboratories to provide effective learning experiences. The survey item that students agreed with the most stated that working remotely with equipment did not interfere with learning. The data support the premise that online laboratories can provide learning experiences that lead students to think deeply and learn material well. Through higher order thinking as they gather and analyze data, students may deepen their intuition about devices/equipment. It goes without saying such claims about developing an intuition relate to equipment or devices where hands-on experience is not essential to understanding the behavior in question. The data also identify the conditions necessary for an online laboratory to provide an effective learning experience: a user friendly interface, lab tasks that require deep thinking, and content relevant to the course.

## Conclusion

Students found the WebLab interface effective and user friendly which helped them to reason about the data and enhanced the learning experience. Their responses suggest learning included higher order thinking that lead to a deeper understanding of the content. As a result of the positive experience, students believe WebLab should continue as part of the course and be incorporated into other courses. Students also indicated that WebLab helped them develop an intuitive feel of how devices work. This finding suggests a new line of inquiry regarding online laboratory experiences. How do online laboratories affect learners' intuition about the devices or phenomena under investigation. What factors contribute to online laboratory experiences deepening learner intuition?

In conclusion, results suggest that when online laboratories are user friendly with coherent and effective interfaces, they provide viable learning experiences characterized by higher order thinking and in-depth understanding.

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