

NETLab: An Online Laboratory Management System

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Ananda Maiti

Indian Institute of Technology, Kharagpur, India

Abstract—Online hardware-based educational laboratories are increasingly being deployed in traditional on-campus as well as Web-based distance-learning courses around the world. An online laboratory generally will consist of several hardware-based remote experiments. However, one particular experiment can be performed at a time by an individual student or a group of students which require a careful scheduling of the experiments. For the proper implementation of an online laboratory an efficient laboratory management system (LMS) is thus essential. Also for an online laboratory, the students need to fully understand the experimental system setup and feel comfortable as in an actual laboratory environment which, however, can be effectively done by adding suitable videos and animations etc. Besides, the students should be able to run the remote experiments, extract, save and analyze the data and submit laboratory reports online. The front end of the laboratory management system should be made browser-based so that one can use the laboratory facility from anywhere. Also, for the teachers, the laboratory management system should include an online evaluation for the quiz/viva-voce, checking experimental data, grading of submitted laboratory reports and feedback for the students.

In this paper, we describe the design and prototype implementation of an online laboratory management system (for use with shared hardware-based remote laboratory resources) which may be employed for running internet-based online laboratory courses for geographically dispersed Institutions.

Index Terms—Online experimentation, online laboratory, remote control, e-learning

I. INTRODUCTION

E-LEARNING has been a topic of growing interest in recent years. It is a group effort, where content authors (educators), instructional designers, multimedia technicians, database administrators, and people from other areas of expertise come together to serve the community of learners.

Online Laboratory is a subgroup of these e-learning systems where the learner or the user interacts and operates the hardware from a remote location. Online laboratories must be operated with a laboratory management system (LMS) that make sure that the experiments being performed generate the desired results and also serve for the other requirements of each individual user.

The primary objective of the LMS is to manage the learners, keeping track of their progress and performance across various stages and types of training activities. The LMS should be able to manage and allocate resources

such as registration, schedule instructor availability, serve instructional material fulfillment, online learning delivery, and authoring system. It should also provide an infrastructure that can be used to create, modify, and manage contents for a wide range of learning environment to satisfy the needs of rapidly changing laboratory education requirements.

The LMS also need to provide a scheduling system that makes sure that each user or a group can use the hardware without overlapping or disturbing the running of experiments of others. Also, there is a need for creating online laboratory facilities across multiple institutions through shared resources. By sharing resources (i.e., remote laboratories and corresponding curricula online) the high costs associated can be reduced. Currently, running an online measurement-based laboratory is an open challenge. Remote control of instruments and the execution of real experiments via the Internet are topics of interest for many researchers.

The LMS should also be able to save the experiment data, retrieve and evaluate and compare data on learner scores, navigation habits and use them to provide content managers (educators) the crucial information on the effectiveness of the content, if combined with specific instructional strategies, delivery technologies, and learner preferences. One such laboratory management system, NETLab, is being introduced in this paper. The system is in use in laboratory education. With LabVIEW for instrument control, the NETLab is being used for teaching microelectronic devices concepts in the courses EC29003 (Semiconductor Devices Laboratory) and EC29004 (VLSI Engineering Laboratory) at the Indian Institute of Technology, Kharagpur.

There have been a number of different approaches [1-4] proposed to develop laboratory management tools for online laboratories. Management of an online laboratory system requires at least the followings:

- Experiment scheduling
- Delivery of assignments
- Performing the remote experiment
- Publishing of the laboratory report
- Interactive session: students and teacher
- Evaluation (viva-voce) and assessment

Web Services are being proposed for distributed applications and have great potential for building online laboratory management system [5]. It needs to manage the local resources on the local area network (LAN) and the remote resources connected by the Internet. Among the other resources to be managed are the computational resources which are managed using Grid Service techniques.

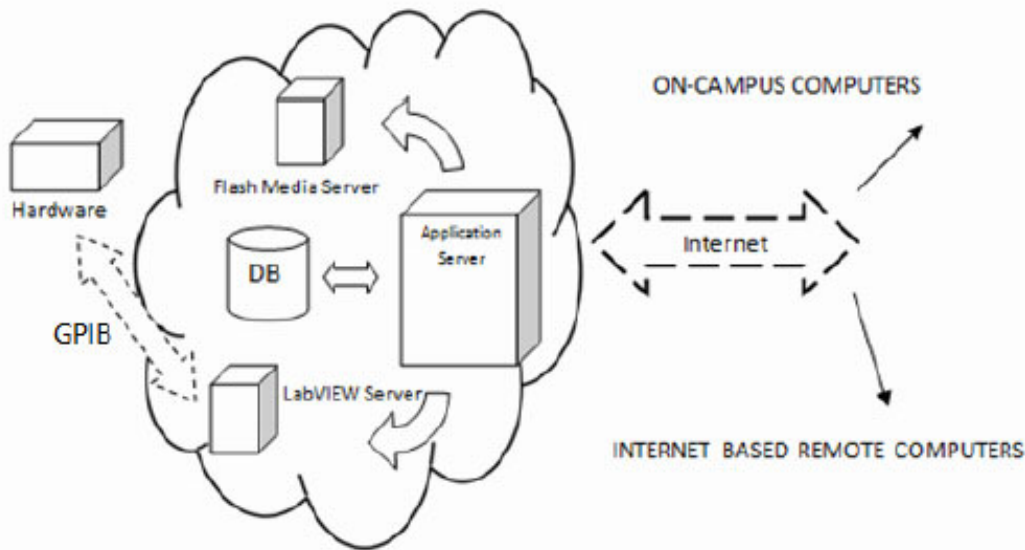


Figure 1. Overview of LMS Architecture

Experimental instruments are managed by Web Services. However, based on rather a simpler configuration, our proposed online remote laboratory is based on client-server architecture and uses off-the-shelf middleware for communication. Products from companies, such as National Instruments (for controlling) and Agilent (for measurement instrumentation) are chosen. Windows™ is the operating system for these instruments and the client side also needs to install proper software to operate the remote instruments.

II. SYSTEM DESIGN

The NETLab uses the following components:

- i. Java server pages and Java servlets as the means to design web pages.
- ii. The back end consists of Oracle 10g. The Oracle Database (commonly referred to as Oracle RDBMS or simply Oracle) is a relational database management system (RDBMS) produced and marketed by Oracle Corporation.
- iii. This system uses JDBC connection to build a connection between the java interface and the database.
- iv. The Sun GlassFish Enterprise Server v2.1 is used as the application server that generates the web pages according to the user inputs. The Sun GlassFish Enterprise Server is a comprehensive support offering for GlassFish, the leading open-source and open community platform for building and deploying next generation applications and services.
- v. The front end is a computer with a JavaScript-enabled browser such as Internet explorer or Mozilla Firefox. JavaScript is an easy-to-use client side scripting language which loosely follows the Java syntax but its design principles are derived from the self-programming language. Currently all the major web browsers (Internet Explorer on Windows, Safari on Mac, Opera, all the Mozilla based browsers) support JavaScript. This assures that the application is OS and browser independent.

The NETLab system has a special interface that connects to the hardware through GPIB card. The overall system configuration is shown in Figure 1. These interfaces are built using the web development tool of NI LabVIEW 2009. The devices are connected and controlled by using the interface and their corresponding drivers.

Each user (student) need to register to get a username and a password (Figure 2). The students profile is also stored in the database. The user has to login and select a particular experiment and proceed. Each experiment has the following features: a laboratory manual, description of the experiment, experimental procedure, etc. As the system works in a batch mode, it distributes the time in slots and each user has to select and choose a particular time slot of his choice for performing the experiment. However, the experiment manuals and other functions are available at all times. Once the student logs on to the system, he has an access to the laboratory and gains full control of the laboratory hardware (experimental setup). The user can adjust experimental parameters or submit new commands in real time. When the allotted time for the experiment is over, the link is broken with a warning. However, the student gets a number of chances to book and perform the experiment till completion. This is done to optimize the use of the laboratory resources so that a large number of students can access the online laboratory.

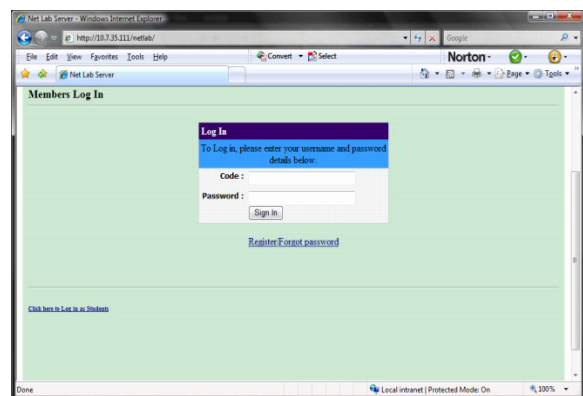


Figure 2. Log In page.

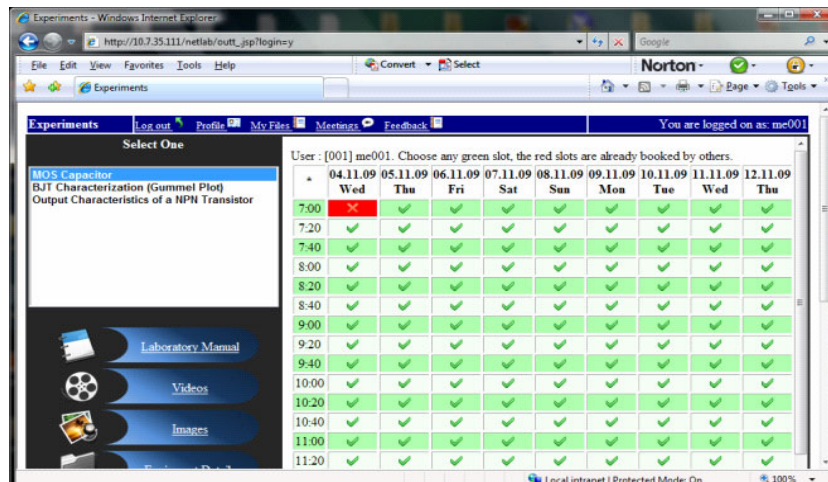


Figure 3. Booking System

After performing the experiment the student need to store the data, plot graphs and analyze the data for the preparation of the laboratory report. Then the student can upload the laboratory report and need to take part in a viva session for evaluation purposes. However, if a student cannot complete the above tasks in one session, he may perform the experiment again.

III. ON-LINE SCHEDULING SYSTEM FOR LABORATORY EXPERIMENTS

Online line laboratory consists of several experiments which the students have to perform in a semester. In the proposed LMS, only one student can choose an experiment at a time from the list of available experiments in the module. A student first needs to find an available time slot and then book the time for the experiment (Figure 3). As the time taken for different experiments are different, a typical runtime may be selected by the instructor and the pre-estimated runtime is provided for the particular experiment. The scheduling system for online experiments described here assumes that the students would be able to finish their experiments in the time slot provided, just like they would do in an on-site laboratory.

In NETLab each experiment is associated a given time slot which the administrator thinks is enough for running the experiment, keeping in view the speed of Internet and other network elements. Pre-experiment learning using laboratory manuals etc. and/or post-experiment data analyses etc. are not included in the experiment time slot for the optimized use of the hardware resources.

The workflow may be summarized as follows:

- The learner selects an experiment
- Then the learner opens the scheduling Web page link in the experiment page
- The system displays the scheduling interface for the next 15 days
- The system displays the available time slots for the selected experiment in green color and unavailable slots in red
- The learner then selects the date for carrying out the experiment in the scheduling interface

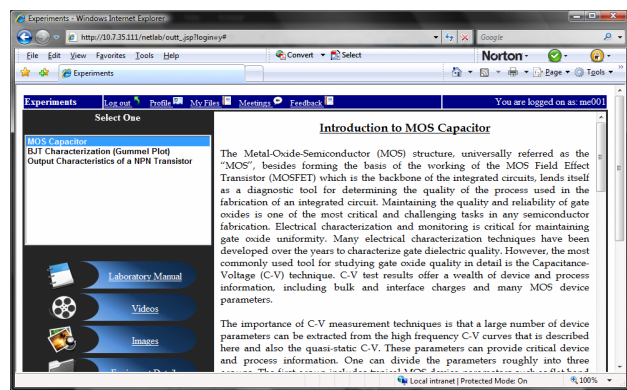


Figure 4. Lab Manual.

- The learner selects a desired time slot from the available time slots and submits the request
- The system saves the learner schedule information and updates the scheduling database
- The system displays a confirmation of the schedule to the learner

IV. LEARNING MANAGEMENT FUNCTIONS

Learning management function modules include authoring tools to generate laboratory tutorials, quiz, and data analyses. An embedded student management system manages the enrollment, marks/grades and progresses of students, and multiple collaboration tools, such as discussion forum, and chat rooms for students to communicate and work.

In the current version of the LMS the functions included are:

- Manuals (pre-laboratory and experiment) contain detailed information about the experiment (Figure 4). These are simple html pages that contain various type of information given in a usual on-site laboratory manual as well as the other detail needed for online interactions.
- The video/image section contains videos and images about different aspects of the experiment (Figure 5). This helps the learners to have a clear concept about the real experiment would be like in a conventional in-campus laboratory. The video and image section is one of the most important parts of the LMS since there is

little direct interaction between student and teacher and the actual experimental setup. The videos/images provide a vivid view of what the actual experiment would look like and build the confidence in the learner about he could do in an on-site laboratory.

- Equipment details section that contains the information about the instruments used in a particular experiment (Figure 6). Every experiment requires a set of unique equipments and/or instruments. These equipments have unique control systems and also specifications. This section describes each of the instruments with both pictures and text which help the learners to be familiar with the necessary instruments. It is expected that the student will be able to perform the same experiment in a real laboratory without any difficulty.
- Interactive Animation section includes animations that would simulate the setting up of the experiment (Figure 7). This is another very important aspect of the NETLab LMS where the learner follows a series of steps in form of an animation that helps the learner to understand the ways to setup the experiment. These animations are built using Adobe Flash CS4.
- Sections involving Question box and video chatting would provide ways to communicate with the instructor and also other students (Figure 8). This feature is very important for collaborative learning as needed in online laboratory education. The learner can use this feature to communicate online with the teacher and ask questions (in case of doubt) which teacher would respond to. In the LMS developed, provision has been made to display all the questions asked by the students and the answers provided by the instructor. Also, further provision has been made for a learner to request for a video conferencing with the teacher to discuss online on the experiment. During above scheduled video conferencing, other students can also join which would help in collaborative learning.

V. EVALUATION OF STUDENT PERFORMANCE

To aid teachers' online evaluation of student performance, provision has been made for keeping track of status at various stages of the experiment for each student and the evaluation is done. The process of evaluation is done in multiple steps as follows:

- Preliminary Quiz is conducted before the learner can access the actual experiment page (Figure 9). This is done online and consists of some random True/False type questions from the theory, manuals on the experiment and the instruments used. Only after checking that the learner has obtained 50% or above marks, the student is allowed to book the experiment time slot. This is done to optimize the use of the instruments and to make sure the students know about the instruments and also the experiment.

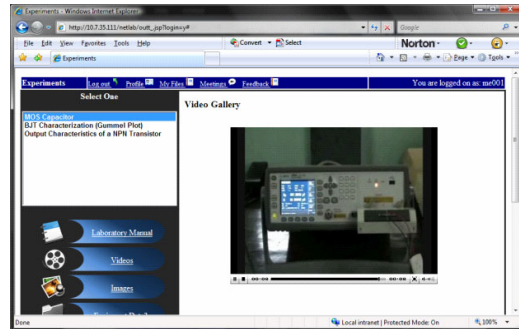


Figure 5. Video Gallery.



Figure 6. Equipment detail.

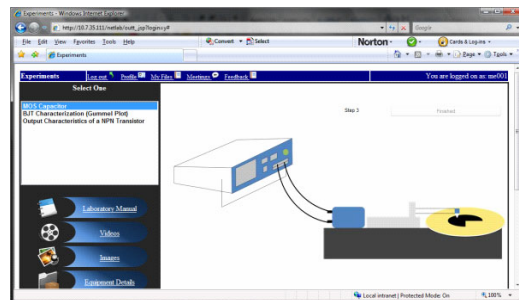


Figure 7. Experimental setup (animation).

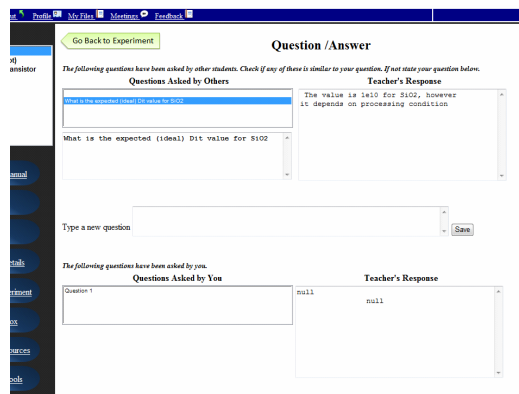


Figure 8. Question/Answer (student feedback).

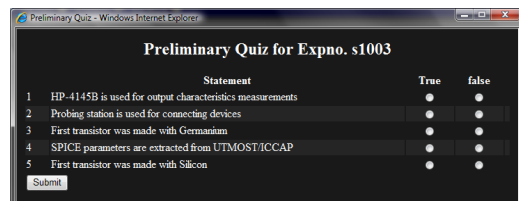


Figure 9. Preliminary Quiz.

- After the Experiment has been performed successfully, the learner needs to save and plot graph etc., analyze data, interpret the results, and extract parameters, if applicable. Provision has also been made for online analysis using tools which may be supplied by the instructor. Once this is done, the student is now in a position to prepare the laboratory report for uploading (Figure 10). The laboratory report must contain the detail on the experiment done as well as the data obtained and results and discussions. However, the report file needs to be saved in a particular format. Once the laboratory report is submitted by a student, it is accessible only to the instructor who may check it manually and grade the student. If necessary, the instructor may send feedback on the experiment to the student and ask for resubmission. Laboratory reports of students are not accessible to others.
- After submission of the laboratory report, the student needs take part in the online viva-voce examination (Figure 11). The viva-voce session requires answering of different types of questions set (already made available in the data base by the instructor). Both the viva-voce session and laboratory report are then graded and a final grade for the student is prepared and uploaded so that the student knows his grade.

VI. EXPERIMENTAL SETUP

When students log on (during booked time) they can access the experiment pages. The html pages contains embedded object which are basically created using the LabVIEW Web development tool [5]. The html files are hosted and distributed by an in-built LabVIEW web Server. The interface in derived from the VI files created in the LabVIEW 2009. During the experiment, the students take over the control of all the equipments and can set the necessary experiment conditions from the user terminal (Figure 12). The measurements are made and the data are transferred to the client's PC. The html pages also contain learner information and display the time left during experimentation. Once this time is over a JavaScript function simply displays a warning alert and then closes the window. The student needs to place at least one screenshot of the html page in the laboratory report to prove that the experiment was done by him.

VII. ADMINISTRATION

The NETLab LMS contain an administrator section for the teachers and administrator to keep control and track of what is going on in the system (Logbook). The teachers can easily check the students' entry/exit records for information for future reference. The administrator can create new experiments by entering information about the experiments such as manuals, videos, images, animations etc. to update the laboratory module. Teachers are permitted to check the student's laboratory report and answer to the student questionnaire raised in the question box. The Logbook section displays information about the student progress, the grade obtained and the time and period when the students performed the experiment.

Following are the results of the students' and instructors activity profile (usage statistics) and opinion about NETLab as a learning tool.

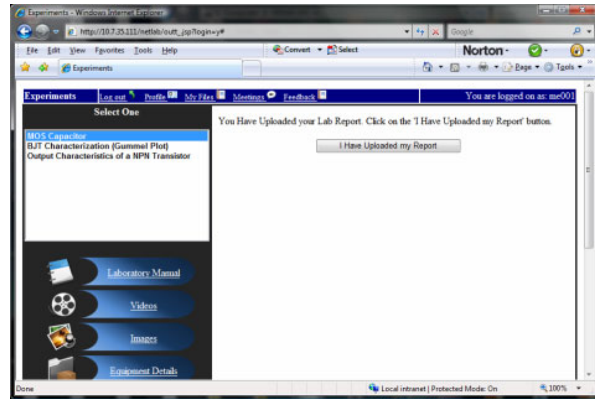


Figure 10. Laboratory report.

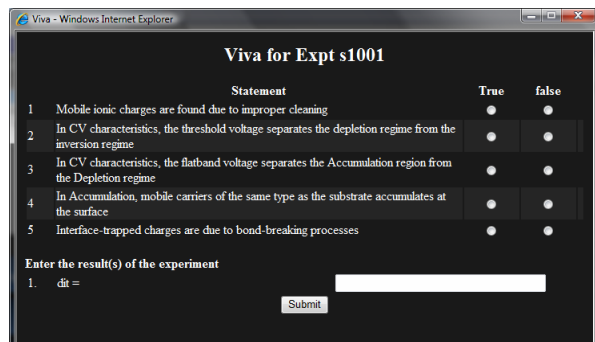


Figure 11. Viva Voce.

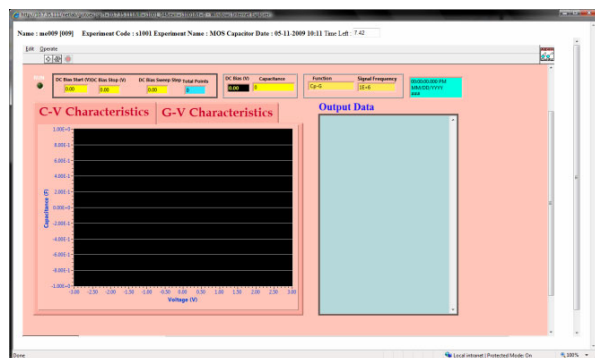


Figure 12. Labview interface.

This study is based on a student population of about 40 in EC29003 Devices laboratory for the period January-April 2009. All the students used the same website <http://203.110.240.33/netlab>, which has the functionality such as choice of experiment, experimental procedure, laboratory manual, pre-laboratory theory etc. Interactive session with teachers and students, as well as an inquiry/feedback, formed the basis for the evaluation. Evaluation procedures consist of several criteria, such as, Very Poor (VP), Poor (P), Fair (F), Good (G) and Very Good (VG) as measures. Student Feedback Form were used regularly which helped in receiving online feedback regarding their laboratory exercises.

Laboratory Assessment Tools were used for evaluating the effectiveness of the Laboratory experiments in terms of pedagogical benefits, resource utilization and cost effectiveness on a regular basis. Analytical Tools were provided in each experiment to help in performing various analyses on the data collected during experiment. Following typical parameters were used for evaluation:

- Freedom of Access
- User Friendliness
- Unmanned Assistance
- Assessment Support
- Experiment's Effectiveness in Learning
- Freedom of Creative Experimentation
- Ease of Modifying experiment
- Skill Developed
- Operational Control
- Availability of Analytical Tools
- Performance Effectiveness

Survey for Devices Laboratory EC29003 was carried out at the end of the semester during Spring Semester 2009. The survey consisted of ten questions and its main objective was to measure the acceptance, usability and usefulness of the NETLab developed at IIT Kharagpur. The evaluation system has been chosen as: marks 6 and 8 are "very good", 1 and 2 "poor" and 3 and 5 "good". With this evaluation system, each student's answers were evaluated. Further, the information obtained from the Logbook may be used for the evaluation of the LMS itself, for example, the weekly utilization information of the laboratory module is shown in Figure 13.

Table 1 shows that the opinion of the students and it is remarkable that the score of the questions related to suitability (Q1), time of experiment (Q5) and satisfaction (Q8) are high showing the effectiveness of online remote laboratory.

TABLE I.
SURVEY RESPONSE.

Question	Score
1. Has NETLab helped you with the Experiment?	8
2. Do you think it is a good idea to have an Internet remote laboratory?	7
3. Is it easy to use?	6
4. Did you feel at comfortable in changing the inputs?	7
5. Was the allotted time for experiment was sufficient?	8
6. What do you think about the inputs/outputs (in webpage) implemented?	6
7. Being not able to see the equipment, how you felt yourself to be in the instrument control?	5
8. What is your overall satisfaction with NETLab?	8
9. Have you ever faced with the server down?	1
10. Were the other available resources useful?	7

Lab-on-Demand statistics

Lab-on-Demand Users during 01.01.2009 - 04.30.2009

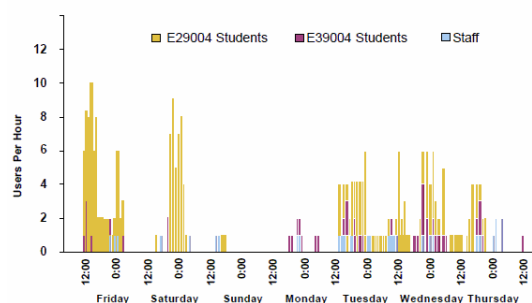


Figure 13. Usage of NETLab showing preference in the weekend.

VIII. CONCLUSIONS

NETLab (Online Laboratory Management System) has been designed and installed for use in the undergraduate and postgraduate "Microelectronics and VLSI engineering Laboratory" at the Indian Institute of Technology (IIT), Kharagpur, India. The system described here currently uses manual teachers' evaluation procedure. Attempts are underway to provide fully automatic online evaluation for both the laboratory reports and viva-voce examination.

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AUTHORS

A. Maiti is an undergraduate student studying computer applications in Vidyasagar University, Midnapur, India (e-mail: anandamaiti@live.com).

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