



Execution of Remote laboratory with Learning Management System

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Abstract

This paper describes the development and execution of a remote laboratory along with a learning management (LMS) system. The paper provides a brief description of an Internet accessible remote laboratory development that includes interfacing of experiments with the facility, graphical user interface design, web server and software tools. In terms of the LMS, the paper provides details of this along with its features for administrative and student levels of access. When offering the remote laboratory, a large volume of data is collected for experience sampling method and weekly survey. An evaluation scheme was implemented to assess the effectiveness of the system as well the students' learning outcomes. In-built capability to collect systems' operational data and weekly survey are used to evaluate the effectiveness of the system, while pre- and post-tests are utilized to measure the student learning outcomes.

1. Introduction

One of the major limitations of distance-learning programs is their failure to deliver the laboratory related courses.^{1,2} For distance learning programs, students currently have to visit a campus to perform the laboratory sessions or there has to be an arrangement of mobile laboratories stationed at a few predetermined locations for a given period of time. These provide limited access to the experiments and are usually insufficient to complete their learning process. Making the laboratory experiments accessible over the web addresses this need.

There are a range of technological developments to support the remote laboratories and a number of attempts have been made to provide students and researchers with practical exercises or experimentation experience over the Internet. Gomes and Bogosyan provide a general overview of these developments as well as the challenges and future possibilities of remote laboratories.³ There are a number of recently reported developments that provide remote access to mobile robotics, automation and control laboratories, robot control, and the most challenging by offering a chemistry laboratory.^{4,5,6,7} In addition to educational applications, it has been demonstrated that the remote laboratory can also be used for industrial applications.^{8,9}

All these initiatives have limitations: restrictions in data accessibility from the clients' end, capable of operating only one experiment at a time, difficult to expand due to custom built software and hardware, lack of in-built system management provision, and subsequent difficulty in maintenance. Furthermore, none of the reported systems are used for delivering a complete regular laboratory course.

To handle some of the problems, the author has designed and developed a modular remote laboratory facility using commercially available hardware and software, in-built password control and user tracking, and accessibility to multiple clients at the same time. Modular design allows the system to adopt a range of experiments with no or minimal changes, while the use of commercially available products made it cost effective and relatively easy to maintain. In-built password control and user tracking provision allow an administrator/faculty to monitor the use of the facility while offering a laboratory course. Accessibility to the facility for multiple clients makes it efficient and cost effective.

This paper will report a brief description of the developed facility, along with the detailed course offerings for a laboratory course. After this introduction, the first section describes the developed facility that has been used for a laboratory offering. The next section provides the details of Internet delivery in terms of web application development and browsing structure. The following section describes the arrangement for laboratory delivery. The fourth section provides the LMS that is used for the offering of this laboratory. The fifth section illustrates the lessons learned, followed by conclusions, acknowledgment, and references.

2. Developed Remote Laboratory Facility

The developed system is a combination of hardware and software. A block diagram of the system is shown in Figure 1. This is composed of a) Experiment bank; b) Switching mechanism; c) Interfacing between the system and the experiment bank; d) Graphical user interface (GUI); e) Access control and user management; and f) Web application for system monitoring.

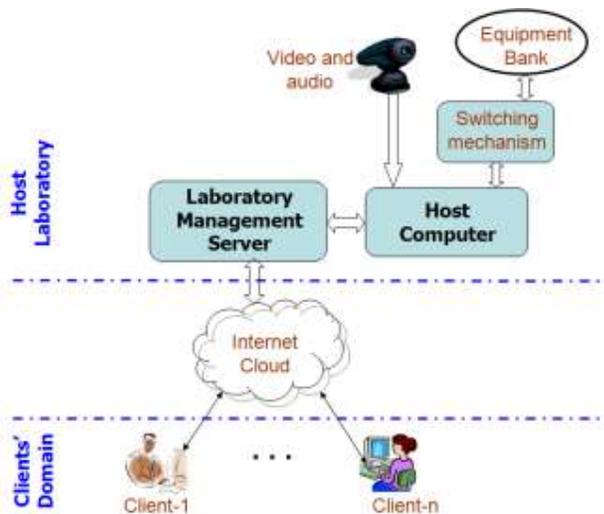


Figure 1: Overall block diagram of the developed system.

Experiments and Interfacing

The Experiment bank consists of all the developed experiments and is connected to the Host Computer via a switching mechanism. The switching mechanism allows one to reconfigure the hardware connection to form different experiment setups.

The developed experiments deal with both the analog and digital signals. An I/O card from National Instruments (NI) is employed as the interfacing hardware. This is a NI USB-6212 PCI-6528 with 24 inputs and 24 outputs and is enough to provide sufficient I/O channels to drive a number of experiments at the same time.^{10, 11}

The software part of the interfacing process was implemented by using LabVIEW, which is also from NI. The LabVIEW software has much more flexibility for data acquisition and control over the Internet. This can also be used along with other third party software, making it more attractive for development applications such as this one. Apart from these, the other reason for choosing LabVIEW is for its inbuilt server facility that can be utilized to publish a GUI as a web page for Internet access.^{12, 13}

Graphical User Interface and Web Presentation

One of the main components of the Internet based laboratory facility is the GUI. This is serving as the media between the experiments and the students. It is important to provide a user-friendly and effective GUI to attract students while performing experiments, as there is no physical supervision or assistance (for remote laboratory) that is usually provided during a traditional laboratory class. For this development, LabVIEW provides a facility to develop a GUI, which can serve both of the above purposes.¹⁴ The concept of GUI is to create more powerful, flexible, and cost-effective instrumentation systems using a PC. A GUI can easily export and share its data and information with other software applications.

Presenting a GUI over the Internet involves publishing the GUI as a dynamic web page. The published GUI is stored within the server at a particular location, and a web application can point to the location and filename for access to the GUI. LabVIEW allows multiple GUIs to be published at the same time, thus allowing the system to handle multiple experiments simultaneously. To publish a GUI as a web page one needs to use the 'web publishing tool' and to follow certain steps using few interacting pages.

Within the web publishing tool, there are options to select the level of control that a client can have once the GUI will be accessed through the web. To provide two levels of access (performer and viewer), each GUI is published in two modes. The former is to allow the user to have full control over an experiment, and the latter is to view an experiment without any control.

Web Server and Software Tools

A web server is hosting the web site for the facility, including all the applications and interfacing hardware and software. In terms of hardware, the web server is having an *Intel Xeon X3370* (12M Cache, 3GHz, 1333 MHz FSB), and National Instrument's I/O card. For the software part, it has Windows 2003 Server (OS), LabVIEW, Internet information services (IIS) server, .NET, XML (EXtensible Markup Language), XSLT (EXtensible Stylesheet Language Transformations), and SQL server 2008. A block diagram showing an overall software interaction is provided in Figure 2.

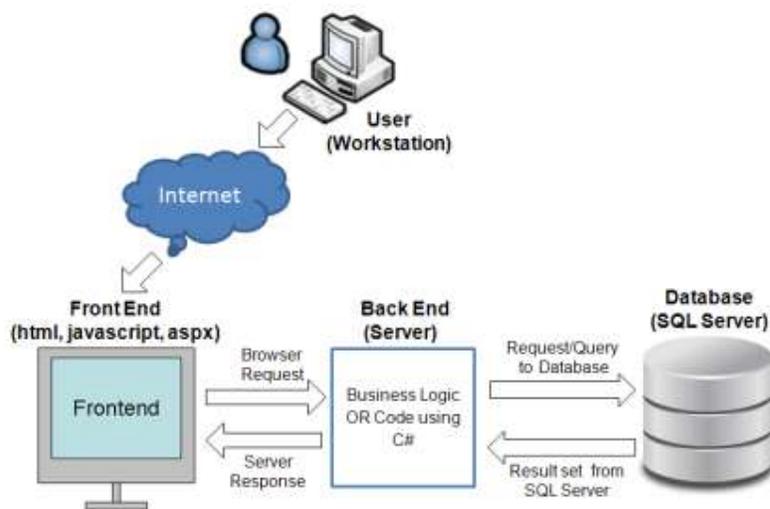


Figure 2: Software interaction scheme.

LabVIEW is also used for data collection, processing, and visualization. The IIS provides the services to the http requests coming through the Internet. This is a component provided within

Windows 2003 server. The IIS makes it easier to share documents and information over the Internet. Web-publishing, security, administration, and applications can work together to increase performance and reliability, while lowering the cost of ownership and also improving the web application environment. Only an authorized client with a valid password can access the system. This requires password protection and a dynamic web page. This has been implemented using ASP.NET.

The .NET Framework is the infrastructure for the new Microsoft .NET platform and is a common environment for building, deploying, and running Web Services and Web Applications. The .NET Framework contains common class libraries like ADO.NET, ASP.NET, and Windows Forms. This is to provide advanced standard services that can be integrated into a variety of computer systems. This is a language neutral framework and supports C++, C#, Visual Basic, JScript (The Microsoft version of JavaScript), and COBOL. The new Visual Studio.NET is a common development environment for the new .NET Framework and provides a feature-rich application execution environment, simplified developments, and easy integration between a number of different development languages. ASP.NET along with ADO.NET is used to build this web application and has used C# as the programming language for its simplicity and completeness.^{15, 16, 17}

Computer systems and databases contain data in incompatible formats. One of the most time consuming challenges for developers has been to exchange data between such systems over the Internet. XML was created to structure, store and send information. Converting the data to XML can greatly reduce this complexity and create data that can be read by many different types of applications. XML can also be used to store data in files or in databases. Applications can be written to store and retrieve information from the store, and generic applications can be used to display the data.

XSLT describes how the XML document should be displayed; in a way they have the same relationship CSS (Cascading Style Sheets) shares with HTML. CSS guides a browser about how the HTML should be displayed. XSLT is used to transform an XML document into another XML document or other type of document that is recognized by a browser, like HTML and XHTML. Normally, XSLT does this by transforming each XML element into an (X)HTML element. With XSLT, one can add/remove elements, attributes to or from the output file, rearrange and sort elements, perform tests and make decisions about which elements to hide or display, and a lot more. Standard Edition of SQL Server 2000 is used as the back-end database for the facility. SQL Server 2000 is a database management system that offers a variety of administrative tools to ease the burdens of database development, maintenance, and administration. These tools are Enterprise Manager, Query Analyzer, and Data Transformation Services. Enterprise Manager is the main administrative console for SQL Server installations. It provides a bird's-eye view of all of the SQL Server installations. One can perform high-level administrative functions that affect one or more servers, schedule common maintenance tasks, or create and modify the structure of individual databases. Query Analyzer offers a quick method for performing queries against any SQL Server databases. It is a great way to quickly pull information out of a database in response to a user's request to test queries before implementing them in other applications, to create/modify stored procedures and to execute administrative tasks.

3. Delivery of Experiments over the Web

The Internet delivery part of this facility involves a number of issues: system access levels, user profile and password control, documentation, experiments, weekly surveys, and administrative activities. All these issues are addressed within the facility to make it as effective as possible.

Similar to the other modules, the Internet delivery module is independent of other modules and can accept any form of experiments without much change. The only thing that has to change is the experiment related documentation.



Figure 3: Homepage with client login access.

The system access level controls the level of access by a facility user. There will be two levels of access to the system. One will be as a client and the other as an administrator. Students will be allowed a client level of access. With this status, they can perform or view an experiment, change password and demographic details, respond to ESM questions, and complete the weekly survey questionnaire. The administrator level of access will allow management of experiments and monitor and gather access profile and survey data. An image of client login page is shown in Figure 3; while an image for the laboratory experiment page is shown in Figure 4.



Figure 4: Web access portal for laboratory experiments.

A flowchart showing the browsing map for client and administrative levels of access is presented in Figure 5.

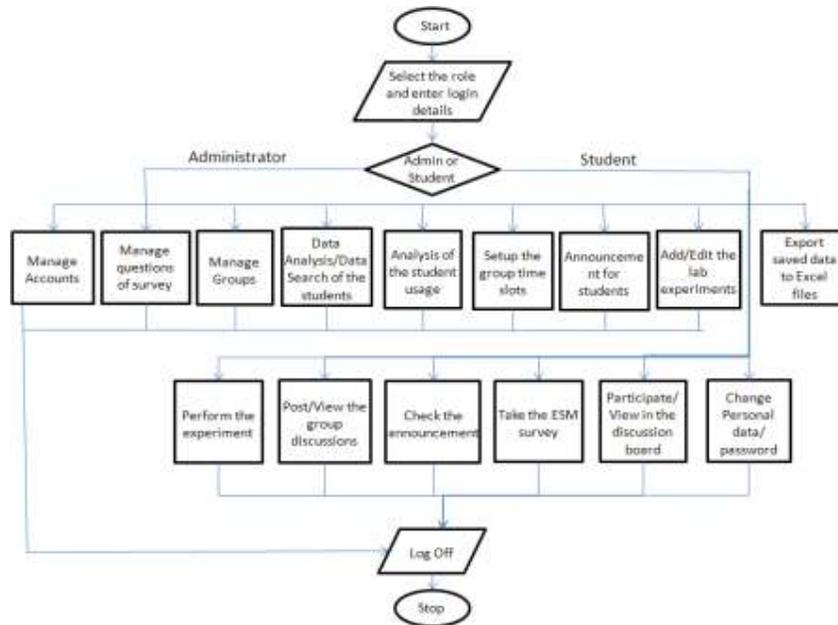


Figure 5: Browsing map for the facility.

Apart from the home page, the client level of access allows the users to have three areas to browse: Documentations, UserProfile, and Experiments. For the administrative level of access, one can activate and deactivate experiments and have access to the user profiles and weekly survey data.

Northern Illinois University offers the Blackboard system for its course delivery, and it has some features that can be beneficial for the delivery of an Internet-based laboratory course.¹⁸ In addition, Blackboard provides an additional level of network security. With this understanding, Blackboard was used as a gateway for the laboratory course offering. The students who were performing experiments through remote laboratory were enrolled in a Blackboard course. A block diagram presenting the weekly cycle of actions is shown below in Figure 6.

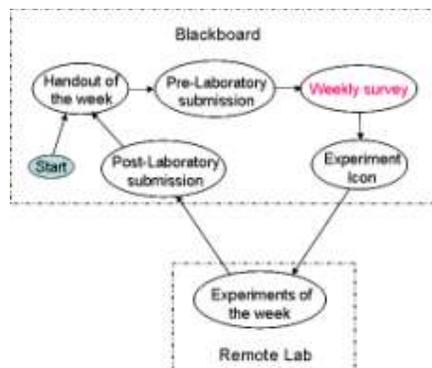


Figure 6: Internet-based laboratory protocol for the delivered course.

The start block shows the starting point for the process. The handout of the week was posted on the Blackboard, and students needed to perform some pre-laboratory tasks. After completing the pre-laboratory tasks, the handout was submitted through the course drop box (within the Blackboard). At the end of each week, students needed to complete a survey considering the previous week's experience with the whole remote laboratory facility. This survey allowed the facilitator to update the system for better performance and also gather perceptions of students about the facility. One

could not have access to the next week's laboratory without completing the previous week's survey. Once within the remote laboratory facility, one could perform all the tasks that posted for each week. The timeline for remote laboratory related posting and submissions is shown in Figure 7.

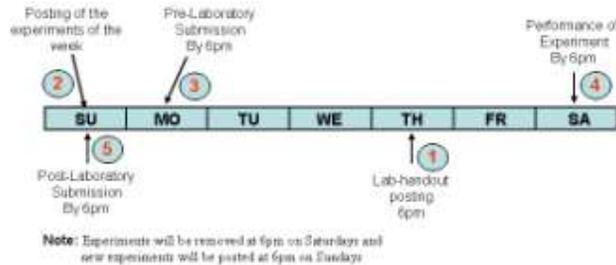


Figure 7: Weekly timeline for the Internet-based laboratory course.

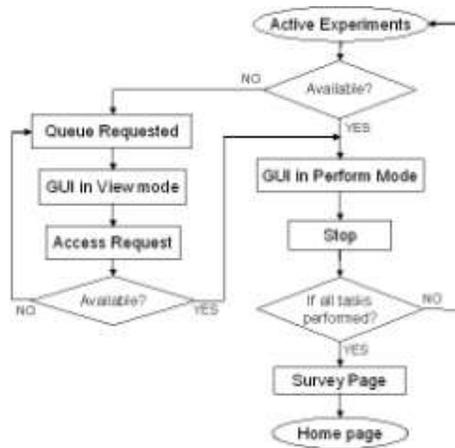


Figure 8: Level of access to the experiments.

A flowchart showing the access levels to an experiment is shown in Figure 8. An experiment can be performed by a single user (performer) at any point in time; while other users (viewers) can only view the experiment without any control over it. Depending on the availability of an experiment, a client can get access either as a performer or as a viewer. Only a performer is able to change the input status for an experiment. There is a software queue that provides access to a client on a first come first serve basis.



Figure 9: Shows the image of administrator home page.

4. LMS for Remote Laboratories

The remote laboratory is offered with a custom developed learning management system.¹⁹ This LMS has administrator and student levels of access. With administrator level of access one can perform a number of activities: laboratory management, experience sampling method (ESM) data management, facility usage monitoring, weekly survey management, and data download. An image of the administrator access page is provided in Figure 9.

The laboratory management feature allows an administrator to manage laboratory groups, group time slots, and laboratory experiments. Experience Sampling Method, briefly known as ESM, is a method of measuring students' engagement on Likert scales indicating enjoyment, concentration, and interest in a given activity. This measurement has been shown to have strong psychometric properties and is positively related to achievement.²⁰ The ESM is used to gather data on the subjective experience of individuals while they are engaged in particular activities.²¹ The software facility provision was made so students were prompted with pop-up windows (while using the environment) to respond to a number of scaled items in which they reported on their concentration, enjoyment, and interest in the activity they are doing at that moment as well as their perceptions of the challenges involved in the activity. The facility usage feature allows an administrator to monitor the usage of the developed facility for a given period of time. Using the weekly survey management feature an administrator can update the weekly survey questions and analyze the data gathered.

Student level of access allows one to perform experiments, take part in ESM activity, and complete weekly survey. An image of the student home page is provided in Figure 10.



Figure 10: Shows the image of student account page

5. Lesson learned

The project evaluation blends various emerging technologies in an innovative manner to develop and validate the remote laboratory facility while offering targeted laboratory courses. The facility is designed and implemented such that most of the data were gathered via the software system while offering the courses. The evaluation process is divided into four parts: a) Assess timely and

efficient project implementation, b) Assess the performance of the environment, c) Assess the effectiveness of the environment for achieving students learning outcomes, and d) Study the use of the environment for students' learning behavior and engagement.

Assess timely and efficient project implementation: The implementation of the project was continuously monitored in terms of the environment development, project design philosophy, and pedagogical design issues. Implementation criteria for each of these issues were laid out at the very beginning of the project. Factors that were considered for this part of the evaluation include the timely completion of various parts of the environment (in terms of hardware and software) and consideration of project philosophy during the pedagogical design.

Assess the performance of the environment: This part of the evaluation helped to establish the performance of the environment in terms of its technical features, usefulness, user friendliness, and generation of the level of interest about its use, interest level in the material, adequacy of background preparation, usefulness of the laboratory handouts, effectiveness of the tutorials, relevance of course materials, and ease of access to the environment. Students also provided suggestions for improvement, overall assessment of the management of the project, and changes of student attitude toward the targeted laboratory courses and general STEM courses. This information was used for quantitative and qualitative analysis as well as the continuous improvement/updating of the teaching materials, experimental facility, and delivery approach. There was an inbuilt data collection system (questionnaire) within the environment. The students needed to complete the questionnaire on a weekly basis.

Assess the effectiveness of the environment for achieving students learning outcomes: Both the formative and summative evaluation were conducted for this part of the evaluation. For formative evaluation, the test- and control-groups were given pre- and post-test at the completion of each topic/stage and differences in achievements will be compared between the test- and control-groups with both descriptive and inferential statistics. For summative evaluation, the student groups were tested at the end of the course to determine their level of mastery of the subject area and their interest level in the topics and applications covered. The students' perceptions of the lasting impact of this project and the effectiveness of vertical integration will be addressed through the performance evaluation of the students during their senior years. Both the test- and control-groups participated in this part of the evaluation. The most important finding is that the remote laboratory group's average gain exceeded the control group's gain (69.08 versus 65.50).

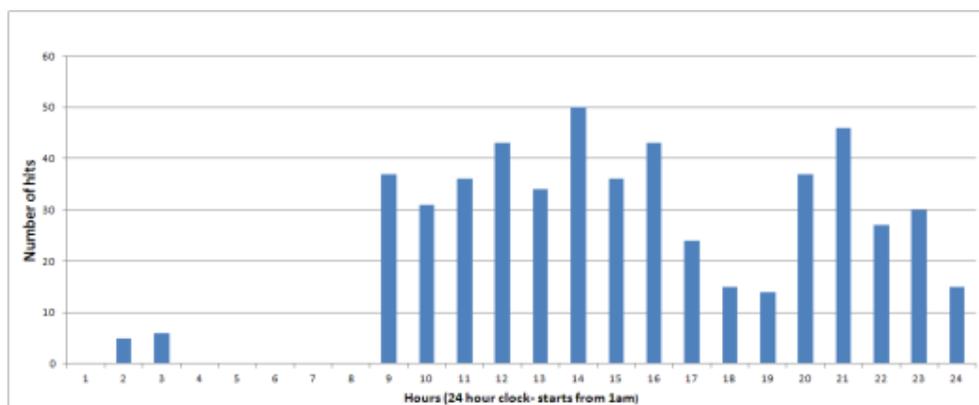


Figure 11: hourly distribution of access to the facility.

Study the use of the environment for students' learning behavior and engagement: To understand the students' learning behavior, data were collected about the individual student's working hours with the environment, amount of time spent on a topic, amount of time spent at various difficulty levels, and the nature of tools (cognitive apprenticeship and scaffolding) that were used. The data collection process was designed as an inbuilt feature of the facility. These data were analyzed from various angles to provide information/knowledge in terms of when, how, and which tool was best for a student's learning for a given circumstance. Only the test-group took part in this evaluation.

Access hours

Within the software environment there was a provision to collect the access time in the facility. This allowed assessing the level of facility usage. A graph showing the total number of hits throughout the semester is shown in Figure 11. The figure shows that the use of the laboratory spread from 9am through 12am; a few students even performed experiments in the early hours of the morning.

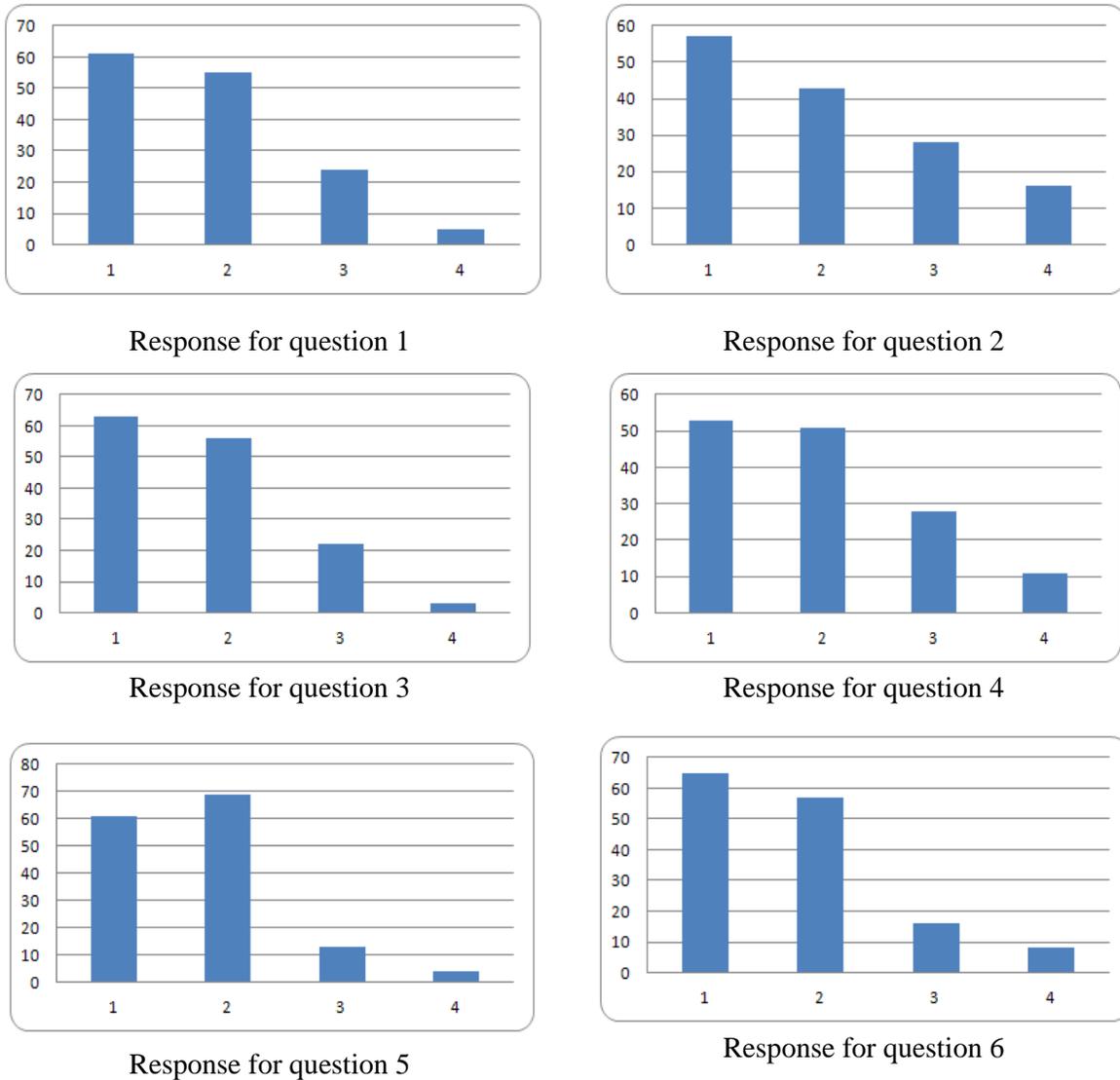


Figure 12: Response graphs for weekly survey data.

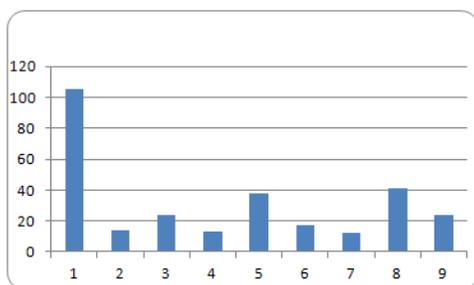
Weekly Survey

The weekly survey was used to assess and improve the performance of the facility and course delivery method. The test-group students took the survey on a weekly basis, and the data were used to review the system continuously. There were a total of nine questions used throughout the semester (questions and possible responses are provided in Appendix A). The survey results are aggregated for each question and are plotted in graphs; only the first six are provided in Figure 12. For all graphs x-axis is the response and the y-axis is number of responses. The question 1 response profile demonstrates that the students felt the remote laboratory as a good idea. The anywhere/anytime nature of the remote laboratory was preferred by the students as shown from the question 2 response profile. From this experience, student also wanted to enroll in remote laboratory courses again in the future. They also thought the level of learning was generally higher for the remote laboratory approach; however, the evaluation outcome did not show much difference between the remote laboratory and traditional hands-on approach. Students also found the supporting materials helpful. On the sixth question, the students found the remote laboratory easy to perform.

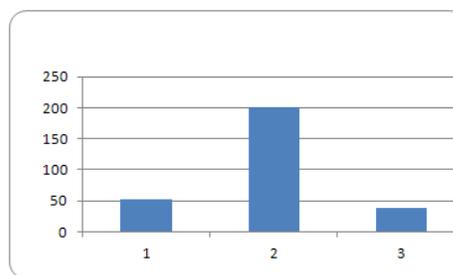
Experience Sampling Method

As mentioned earlier, ESM was used to measure the students' engagement. There was a total of 20 questions (provided in Appendix B). The students were prompted with pop-up windows (while doing experiment via remote laboratories) to respond to a number of scaled items in which they reported on their concentration, enjoyment, and interest in the activity they are doing at that moment as well as their perceptions of the challenges involved in the activity.

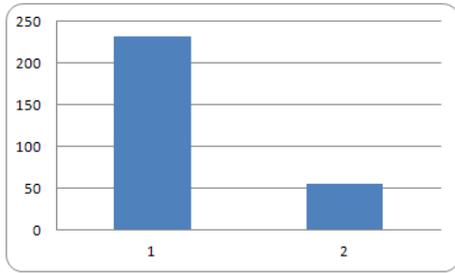
The results show students are engaged throughout the process. The graphs of the question aggregated responses for all students throughout out the semester are provided in Figure 13. For all graphs, the x-axis is the response and the y-axis is number of responses. Within the first pop-up window there were five questions, and these are mainly to establish their personal circumstances at that point in time. In most of the cases, the students were happy; they performed the lab from home and were alone while doing so. It also shows that the students were multitasking for little less than half the occasions and they were repeating an experiment half of the time. The second pop-up window asked questions about their task related feelings (what they are doing at that point). There are a total of 15 questions in this group. These items were answered on a 4-point scale. From the graphs, it shows that for the most part the students were engaged and were taking the activity seriously.



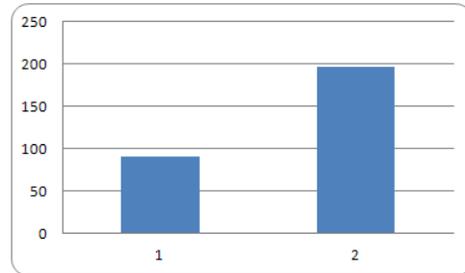
Response for question 1



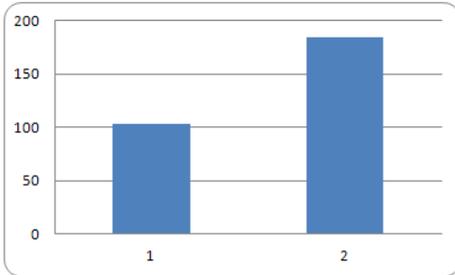
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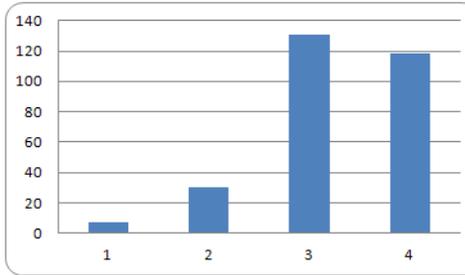
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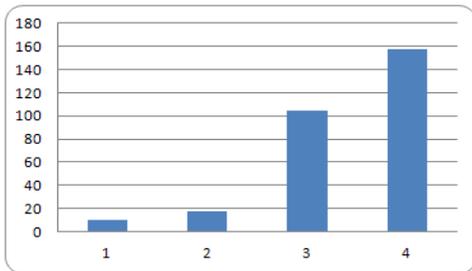
Response for question 4



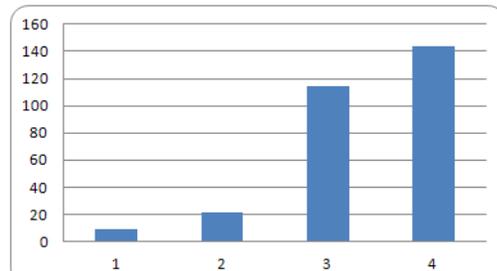
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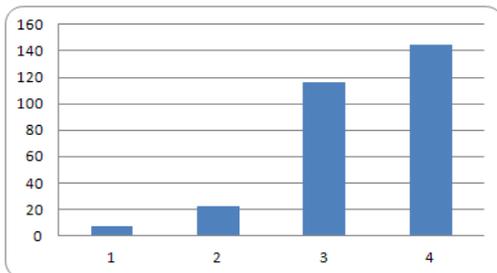
Response for question 6



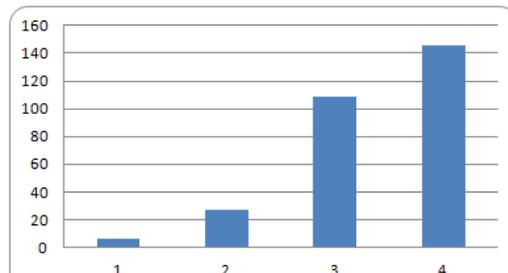
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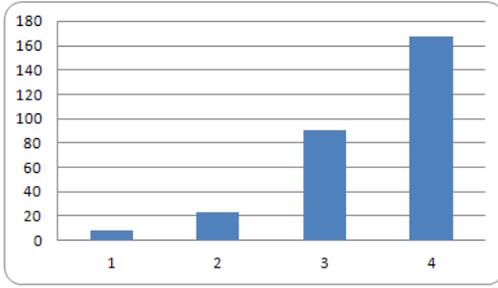
Response for question 8



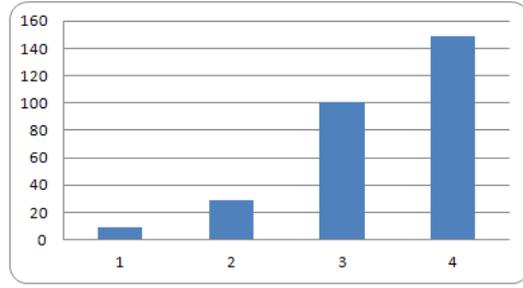
Response for question 9



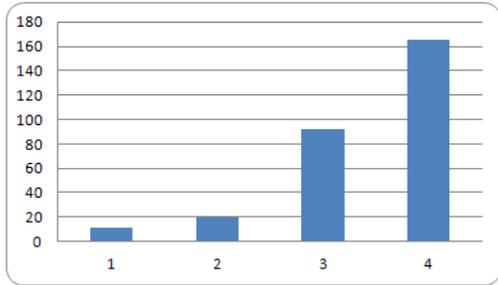
Response for question 10



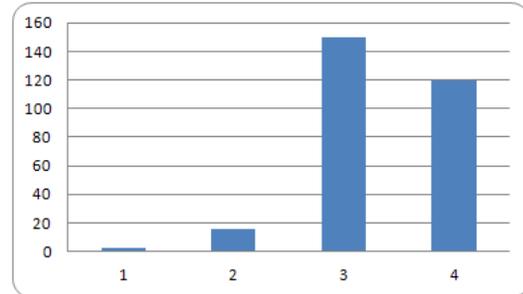
Response for question 11



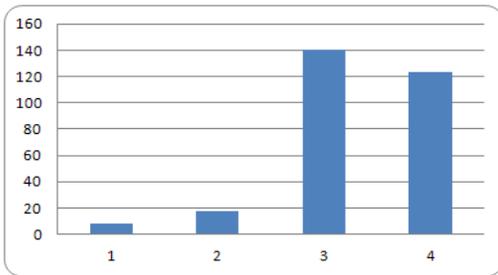
Response for question 12



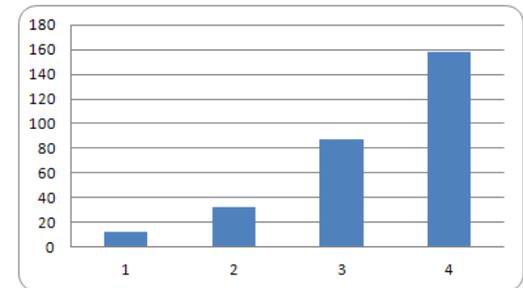
Response for question 13



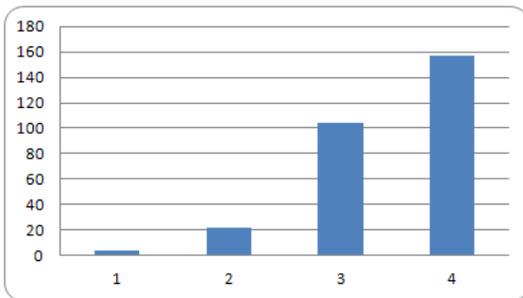
Response for question 14



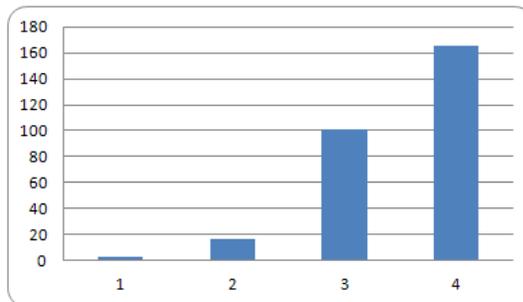
Response for question 15



Response for question 16



Response for question 17



Response for question 18

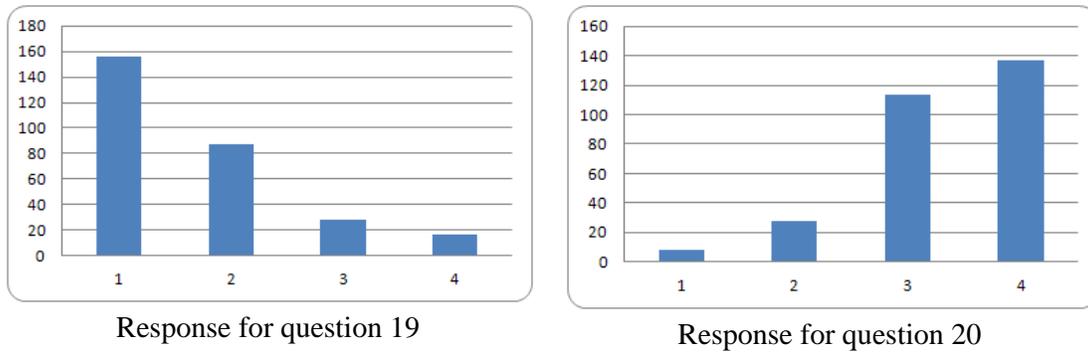


Figure 13: Response graphs for ESM data.

6. Conclusions

The paper provides an illustration of a remote laboratory system along with details involved in offering laboratories over the Internet. The start of the paper describes the development of modules for a remote laboratory, including the GUI and its web presentation. The paper also details the delivery of experiments using an LMS that is custom designed for remote laboratory operation. The final part of the paper describes the laboratory offering mechanism, pedagogical design, and collected data analysis and interpretation. The evaluation results indicate that the students achieved the learning outcomes similar to the students who were doing experiments in a traditional way. Another important issue is the access to the remote laboratory around the clock, which is not possible within a traditional laboratory setting. To assess the student engagement, ESM was introduced, involving 20 questions. It shows that most of the time students performed the experiments from home while they were on their own. Sometimes they were multitasking and sometimes repeating experiments. In terms of engagement, the responses show that the students were engaged most of the time.

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Appendix A: Weekly Survey Scheme

After performing weekly experiments the students needed to complete the survey questions via the remote laboratory software environment. These surveys were to understand the user friendliness of the system and the students' interest level in this approach. The feedback was to be used for continuously improving the system for better performance.

Questions for Weekly Survey

Student will answer the following question based on their experience in using the Internet-based laboratory facility.

Q1: The Internet-based laboratory facility is a very good idea:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q2: The anywhere/anytime nature of the Internet-based laboratory facility is a useful feature:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q3: I would prefer to take another laboratory course over the Internet:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q4: From my own perception I think the level of learning with Internet-based laboratory is similar to the traditional facility:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q5: Support materials provided for the Internet-based laboratory facility were useful:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q6: Performing experiments over the Internet was easier than I expected:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q7: The amount of work associated with the Internet-based laboratory experiments is more than I expected:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q8: The navigation through the Internet-accessible laboratory environment was user friendly:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q9: In comparison with other usual sites I rate the speed of this site as quite high:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Appendix B: ESM Data Collection Tool

Typically, the Experience Sampling Method (ESM) involves several questions each time a person is signaled to respond. In this case, students will be provided with pop-up windows that will have the ESM questions. Most of the questions are Likert-type, while others are multiple choice. There will be no open-ended questions, as these items are very resource-intensive and beyond the scope of the project. In this project we are using two pop-up windows (one after another) that will cover all the questions. Each time it will take 1 minute or less to answer these questions, and the students must (software lock) answer these to move forward with their tasks. The questions will measure cognitive, affective, and motivational dimensions of the respondents' experience. All the identified ESM questions are provided below and are grouped in the order they will be presented to the students:

Pop-up Window-1

Describe your mood as you were signaled (choose only one):

happy
frustrated
stressed
angry
excited
proud
bored
competitive
cooperative

Location

Campus
Home
Others

Environment

Alone
Company

Multi-tasking

Yes
No

Repeating experiment

Yes
No

Pop-up Window-2

Indicate how you felt about the activity you were doing just before the window showed up:
(Each of these items is on a 4-point scale: 0=not at all, 1=a little, 2=somewhat, 3=very much)

Did you enjoy what you were doing?
Did you feel good about yourself?
How well were you concentrating?
Were you succeeding at what you were doing?
Were you learning anything or getting better at something?
Were you living up to your own expectations?
Were you living up to your teacher's expectations?
Did you feel in control of the situation?
How hard were you working?
How challenging was it?
How skilled were you at it?
Was it important to you?
How important was it to your future goals?
Did you wish you were doing something else?
Was this activity interesting?