Principles for the Design of a Remote Laboratory: A Case Study on ERRL

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***Abstract*-- Remote laboratories are getting very popular in engineering education programs. However, there are not many studies addressing the requirements and design issues of such laboratories. This paper discusses the results of a study of the requirements for developing a remote Radio Frequency (RF) laboratory for university students. This study draws on the perspectives of the students at the university, department of electrical engineering. The results are based on a research study established by 111 engineering students from France, Germany, Romania and Turkey. It investigates how students would like to use the technical content of a state of the art RF laboratory. The result of this study is also compared with the previous outcomes showing perspectives of the other learner groups of such laboratories; engineers and technicians in the technical colleges on the Radio Frequency (RF) domain. Considering the outcomes developed so far, some principles that need to be considered while designing and developing such a laboratory have been proposed. As a case study the proposed principles are implemented in a remote laboratory project. In this paper, the details of user requirements of such laboratories, the proposed principles and the implementation examples are all provided and discussed. Primarily, the general aim of this study is to guide remote laboratory platform developers towards the most effective design of their platforms.**

Index Terms— higher education, engineering education, remote laboratory, distance education, Improving classroom teaching, lifelong learning.

I. INTRODUCTION

Nowadays, based on new technologies, educators and curriculum developers are able to provide a wide range of educational alternatives for learners. Remote and virtual laboratory environments are some of these alternatives which have shown that they are potential solutions for supporting current education and providing some alternative solutions for distance learning environments [2]. However, in literature, not many studies discussing the requirements of those laboratories and the instructional design issues that need to be considered in the design of such laboratories could be found. Furthermore, as Koohang and Durante reports, the web-based distance learning technologies rely on interface design elements such as usability, visualization, functionality and accessibility which play an important role in learning [3]. Accordingly, appropriate learning theories and principles as well as user interface elements need to be considered in the design of such laboratories [3]. In our previous studies, we have discussed the requirements for remote RF laboratory applications from the educators' [2], the technicians' and engineers' [1] perspectives. This paper aims to find out the requirements from the students' perspective which is organized for the European Remote Radio Frequency Laboratory (ERRL) project[1]. How do the students prefer to study in a remote laboratory environment is the basic question of this study. The study is established on potential students of such a laboratory environment: students in higher education institutions. The main scope of this study is limited to the instructional content design issues for such laboratories. The issues that need to be considered in the sense of user interface design of such laboratories are not included in this study.

II. COURSE DESCRIPTION

Instruction can be provided with several different forms in a remote laboratory environment such as text, animations, images, figures, interactive content, video and sound based instructions. In literature several studies have been established to find the effect of these different forms of instructions on different learner groups. Those studies show that, the preferences of the target learner groups and actual performance on these different forms of instruction also differ. For instance, reading a text requires linear information processing and significant skill and effort [4]. Differently from the test, pictures' symbol system is sensory and more efficient for representing nonlinear relationships among objects [4]. According to Mayer, visual presentation of learning material enhances learning [5]. From their study, Bele and Rugelj suggest including verbal and pictorial representations for each learning page and additional animations should also be provided for the choice of the learners [6]. Mayer also suggests using words and pictures in ways that promote meaningful learning: adding pictures to words, eliminating extraneous words and pictures, placing words near corresponding pictures, and using conversational style for words [5]. Research also shows that, combination of text plus line drawings shows clear advantage in learning process [7]. On the other hand, from their study, Bele and Rugelj suggest an interactive question for the design of each learning page for immediate knowledge evaluation [6].

[1] Guest access is available at http://errlmoodle.atilim.edu.tr/ with both user name and password being "visitor"

Additionally, studies also show that students' preferences on web-based instruction for linear or non-linear ordered instructional design is also different [8]: older students prefer direct instruction. Students who are more familiar with the windows-based computer applications tend to prefer non-linear instructions. These studies show that, organization of the content and design of the instructional material as well as the feedback system are quite important for improving the performance of the instructional systems. Accordingly, before an institution can offer the most effective remote training for learners, a requirement analysis must be conducted. This study was implemented in the ERRL project in order to identify the requirements from the learners' perspective.

II. DESIGN OF THE STUDY

This work initiates from the belief that the requirements should be clearly defined before technical and practical development of a remote laboratory. The remote laboratories have two main potential groups of users: the educators and the learners. This study mainly focuses on the requirements of the learners from such a system in order to answer the following research questions:

- How students prefer to use a remote laboratory environment?
- Do they need guidance and help while studying a subject?
- In which order do they prefer to study subjects (linear / non-linear)?
- How do they like the content to be displayed?
- What are the students' attitudes toward computer mediated communication?

To answer the questions above, a questionnaire was prepared for the students as potential users of a remote laboratory. This questionnaire[2] was presented to 111 potential students from different European countries: France, Germany, Romania and Turkey. The distribution of the subjects of this study among those countries is shown in Table 1. All of the subjects are under the age of 25.

Table 1. Distribution of the Subjects among Countries

	M %	F %	Σ %
France	11 (10%)	1 (1%)	12 (11%)
Germany	14 (13%)	1 (1%)	15 (14%)
Romania	37 (33%)	16 (14%)	53 (48%)
Turkey	24 (22%)	7 (6%)	31 (28%)
Total	86 (78%)	25 (22%)	111(100%)

M: Male, F: Female, Σ: Total

[2] http://www.atilim.edu.tr/~nergiz/ERRL_Questionnaire_students.pdf

As seen from Table 1, most of the participants are male (78%), which is usual according to the general gender distribution in this field. After the analyses of the requirements of the potential learner groups, the ERRL content is developed to better address the learners' requirements.

This paper analyses the target learner groups' requirements from a remote laboratory environment as a case study, describes how the ERRL content is designed to better address these requirements.

III. RESULTS

The following section analyses the results of this study according to the research questions: the quantitative data is analyzed descriptively. Since the number of female participations was very limited the results do not have gender comparisons.

A. Need help and guidance

The participants' general preferences were asked while studying any subject. According the result of this question is shown in Table 2. Most students; 55% prefer studying with someone who knows the subject well. Their second preference is studying on their own and lastly they prefer to study in groups. In our earlier study [1], this preference order was found to be similar for engineers 50%, 29% and 21% respectively. However, the technicians' second preference found studying within a group (40%) and the third one was studying on their own (13%). In that sense, technicians' preferences found to be different from the students' and engineers'. This shows that the students and engineers in general are not comfortable while studying within a group.

Table 2. Study Preferences

Q4. When learning a new subject which one do you prefer? *(Please Select only one)*	Σ %
Studying with someone who knows the subject well	55
Studying on your own	29
Studying within a group	16

Σ: Total

This result shows that, technicians do not feel as comfortable as other groups of learners while studying on their own and they need more guidance according to the other groups of learners. Most of the students (59%) believe that they need guidance while studying a new subject (Table 3).

Table 3. Need for Guidance

Q6. Do you need to be guided when learning a new subject? (Please select only one)	Σ %
Yes, I need someone to teach me	59
No, I can handle it on my own	41

Σ: Total

On the other hand, 41% of all students feel comfortable while studying on their own.

B. Preferred order (linear / non-linear)?

As shown in Table 4, most of the students (60%) prefer to study the concepts in a linear order: starting from the beginning and going through the chapters in an order. The non-linear ways of learning approaches (keyword search, read the related chapters only, and do exercises only) are their less preferable alternatives. The situation was found to be similar for engineers and technicians in our previous study [1]. However, technicians never prefer keyword search or study only the end of chapter exercises alternatives. Additionally, the percentage of technicians that prefer linear way of studying (73%) is higher than that of engineers (63%) and students (60%).

Table 4. Perceived Learning Preference

Q5. Which of the followings best matches with your learning abilities? (Please select only one)	Σ %
Starting from the beginning of the subject and go through the chapters by order	60
Searching on the keywords (by using search engine of the site or the index part of the book) and then studying on the results	17
Read the chapter that you want to know and leave the rest	14
Trying to understand the end of chapter examples & questions never read the rest	9

Σ: Total

When the similar question is asked for the web environments, the ratio for the keyword search gets higher (Table 5). On the web, technicians, engineers [1] and students also behave differently from their traditional way of learning environments. For instance, most of the technicians and engineers prefer non-linear way of instructions on the web (reach information by means of keyword), where as in the case of traditional ways of studying they mostly prefer the non-linear ways Table 4 [1]. This finding may be a sign to show that when they have a chance to reach information directly they use this feature and their habits are changing through non-linear ways of studying by the introduction of the advanced technologies on the web.

Table 5. Perceived Learning Preference on Web

Q7. When you try to learn a new subject by using a web-site, how do you prefer to study? (Please order the items below according to your preference, 1 is the most preferred one)	Σ %
Go trough the chapters in a given order one by one	36
Reach the information by means of keywords and read only the chapter you need	39
By means of questions and answers between the system and you	25

Σ: Total

C. Display of Content

When the participants' preferences were asked on the ways of the display of the content, in the first place all students prefer interactive content. While engineers' preferences are similar to the students' preferences, it is observed that technicians' first preference is figures on the subject [1].

Table 6. Preferences for Computer Based Experiments

Q8. When performing experiments on a computer I prefer: (Please order the items below according to your preference, 1 is the most preferred one)	Σ %
1-Interactive	17
2-Batch jobs	9
3-Story based	11
5-Figures on the subjects	10
6-Several problems and exercises	12
7-Games related with the subject	10
8-Animations on the subject	12
9-Text-based instructions	11
10-Sound-based instructions	8

Σ: Total

D. Attitudes toward Computer Mediated Communication

In order to identify the participants' attitudes towards computer mediated communication, the advantages and disadvantages of such platforms were asked. Table 7 and Table 8 show their responses on this issue. As seen from Table 7, the students find the geographic independence as the most important advantage for computer mediated communication.

Table7. Advantages of Computer Mediated Communication

Q10. Please select the advantages you consider important for you in computer mediated communication	Σ %
1-Geographic independence	31
2-Temporal independence	20
3-You are not embarrassing for teacher's presence	7
4-Silent (nobody disturb you)	16
5-You can find quickly elements of all past communications	26

Σ: Total

The second one is listed as the finding quickly the elements of all past communication. Temporal independence follows this and silence comes next. According to students, the least important feature of the computer mediated communication is the embarrassment of the teacher's presence. Table 8 summarizes the disadvantages of the computer mediated communication according to the students.

Table 8. Disadvantages of Computer Mediated Communication

Q11. Please select the disadvantages you consider important for you in computer mediated Communication	Σ %
1-Absence of immediate feedback for asynchronous communication	32
2-Imperfect technology	17
3-Not yet sufficient experience with the web and the Internet	8
4-Reading online especially if the amount of information to be read online is significant	27
5-You may not be certain whether other participants have received your message	16

Σ: Total

As seen from Table 8, the most important disadvantage is the absence of immediate feedback for the asynchronous communication (32%). Reading online follows it. Imperfect technology and not being sure whether other participants have received your message come next. Students mostly feel that they already have sufficient experience with web and internet. However, according to the engineers and technicians, the most important disadvantage is found to be the difficulty in reading the online feature of the computer mediated communication (39%) [1], where as for the students this percentage is 27%. This shows that, the younger generation feels more comfortable reading online.

IV. A REMOTE LABORATORY IMPLEMENTATION

As a summary, depending on the first and previous studies, it is possible to conclude that, user requirements and preferences change among different learner groups. Because of the variations in different learner groups' preferences (the students and engineers are in general not comfortable while studying in a group), the technicians need more guidance according to the other groups of learners (while studying, technicians never prefer keyword search or studying only the end of chapter exercises), the percentage of technicians that prefer the linear way of studying (73%) is higher than that of engineers (63%) and students (60%).

General Characteristics of the Learner Groups

- The ratio for the keyword search is getting higher while studying on the web
- Sound based instructions are least preferred
- Interactive content, problems and exercises, animations and figures are preferred forms of content display
- Geographic independence and quickly finding elements of all past communication are listed advantages for the computer mediated communication
- Absence of immediate feedback and reading online are the most important problems of the computer mediated communication.
- The younger generation feels more comfortable as they read online
- The learners' habits are changing through non-linear ways of studying by the introduction of the advanced technologies on the web

E. ERRL Design Principles

As a remote laboratory implementation in the ERRL project, the following principles have been followed as the guidelines for the design of the ERRL system.

Instructions for different learner groups should be provided differently:

From the requirements study, it is understood that the different potential learner groups' requirements and expectations from the ERRL system also differ. In order to satisfy this requirement, the following design approaches were used: Reading texts in the study theory part and experiments are arranged according to these needs of different learner groups. Therefore, the content is divided into three levels as; basic, intermediate and advanced. That is, the content is simplified or enlarged according to the learner groups' requirements. Also, the ERRL platform is designed as flexible enough for offering the possibility to change the lectures from a semester to another and to add new experiments that correspond to these lectures. For this, the content is defined in the ERRL system as learning objects which defines smallest units of instruction that can be reused in different contexts [11], [12].

Support both linear and non-linear presentation of the content

From the study of requirements, it is understood that, in web-based environments, learners' intention on non-linear instructions become higher. However, they still prefer to use the linear way of studying materials. Accordingly, the ERRL system, providing both ways of instructions, has been designed. Learners do not necessarily have to follow each instruction in the system in a linear order. They shall be able to just reach the necessary information which is needed at the moment of the work. Accordingly, the system must be self-directed and also have to support non-linear instructions. For instance, if an engineer tries to get a little information about a feature of specific equipment and if the learner has to go through the whole content, it might also be boring or annoying. The system must provide the necessary information at the moment of need. On the other hand, the system should also support linear instructions and guidance whenever needed. In the ERRL system, the learning content in different studying orders has been designed to satisfy requirements of different learner groups. The instruction is provided in a highly guided manner. All the necessary instruction is given in a predefined order for beginners. Parallel to this, the same instructions are organized as an experiment manual that shows the instructors in order to quickly start the experiment for intermediate or advanced level users. Similarly, in the design of the teaching tool on how to use each piece of equipment, the search facility and the questioning and answering features are added. If the user needs some specific information about any piece of equipment, then learner can write the keyword or ask the question in the text field of "Search for:" part of the system. When the "Submit" button is clicked the results of the search will be shown in the right part of the system again. These results are listed as links in the form of text documents, videos, audios or other forms that are available in the Learning Management Systems' (LMS) database. On the other hand, experiments and study theory parts of the ERRL includes many hyperlinks providing direct access and guidance about equipment and content. In this way, the user doesn't have to linearly search all content in order to find the related material.

Forms of Instruction - Not many sound-based instructions

The ERRL content has been developed and distributed into different skill levels considering the target user groups' requirements. There is very limited movie or sound based

instructions in the ERRL system as alternative for the other forms of the instructions. In this way, the users can select the proper content for themselves and the learners are free to study the concepts repetitively in different forms of training. Also, where possible, the lectures include suggestive animations and simulations that decompose and describe the physical phenomenon under study, in order to be clearly and appropriately understood by the students. Interactive animations used within the lectures can allow for a multitude of scenarios, creating unique situations in response to student inputs.

Providing interactive content such as exercises and experiments

As it is suggested by the literature, the experiments and exercises are very important for the engineering education [10]. Accordingly, the ERRL system is designed to provide as many exercises as the learners want to practice in a specific content. As seen from Figure 1, the learner can set the experiment parameters and repeat the experiment several times.

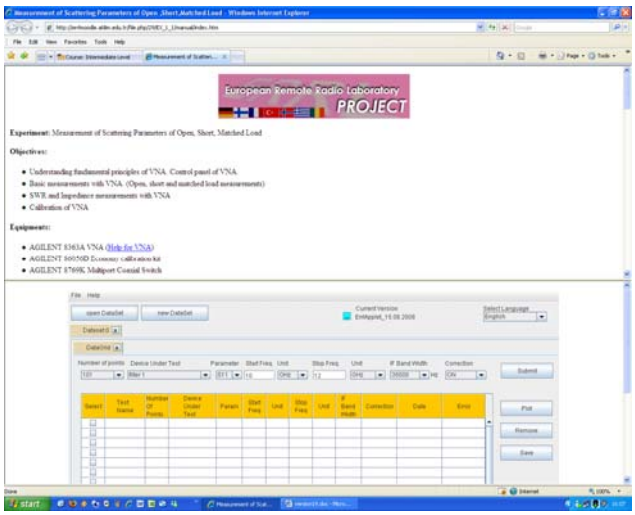

Figure 1. ERRL Experiments

This activity also provides trial-and-error type of learning approach for the ERRL learners.

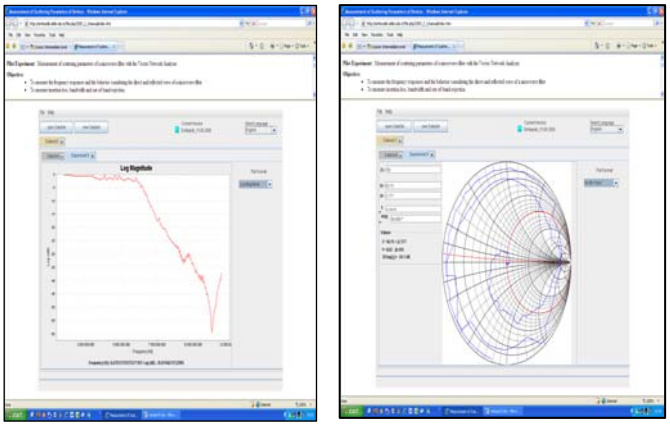

Figure 2: Analysing Experiment Results

As seen from Figure 2, they are also able to analyze the results by showing them in different graphical formats such as Smith Chart and Log Magnitude, to compare and choose the most suggestive one.

Providing a good feedback system

In the ERRL system, in order to provide feedback on the learning performance for both learners and instructors, the assessment system is organized as a skill level test, experiment and equipment test. A Skill level test is advised to be taken immediately after the registration of the system. It can be taken as many times as the learner requests. The main purpose of this test is to understand the beginning skill level and progress in the skill level of each learner. These pre-course assessments that identify areas where relevant background knowledge is missing or prone to misconceptions can serve to revise the curriculum, encouraging talk and curriculum development between instructors both within and across departments.

Experiment tests are applied immediately after the implementation of each experiment. Tests are generally short, and as they are multiple-choice, they are useful for immediate quantitative assessment of student understanding. The experiment user interface covers both theoretical backgrounds for the experiment as well as the experiment itself. The ERRL on-line tutorials with built-in assessments or interactive components combine instruction and assessment. Feedback from assessments, such as item analyses, can be used to inform instruction, enabling the instructor to target the specific components of the lessons that students find troublesome. Another assessment used method is: immediately after studying each experiment. The experiment test items cover both theoretical and experiment specific issues to be tested based on the objectives of the experiment. Each test item about the experiments is defined by describing the following details. Accordingly, each item in an experiment test is defined by its objective as well as if it serves for one of the knowledge, skill or competence purposes. There are at least 3 test items for each experiment objective. Also the number of knowledge, skill and competence type questions is evenly distributed throughout each test. In order to pass the experiment exam, learners are usually asked to be successful for at least 70% of each knowledge, skill and competence type of questions. Learner's current skill level is calculated by using the experiment test results. According to the request of the learner, a summative evaluation report is prepared to show the progress of the learner from the starting point to the current level. This report is based on the learner's progress on each skill level. More detailed reports on learners' progress in each test as well as each test item and an advisory report is also prepared for the learners to better facilitate their learning.

Another test that is implemented in the ERRL system is the equipment test. The main purpose of this test is to assess the learners' knowledge level on each piece of equipment. Learners are asked to pass this test before starting any experiment that requires specific equipment to be used. However, some skills such as the ability to handle the

measurement devices may not be easily assessed. Accordingly, the questions are organized to focus on the equipment construction, how it works and the measurement possibilities. The equipment test content is prepared specific for each piece of equipment; however the testing system strategy is the same for the experiment tests.

V. DISCUSSIONS AND CONCLUSIONS

In this study, the learners' requirements specific to this case study have been collected and analyzed. The ERRL system has been developed based on these principles. The feedback from the sample groups from different countries demonstrated that the above principles are a good approach for the web-based learning and provided us the necessary certainty to continue the work in this direction. For future studies, this system is planned to be integrated into the curriculum and will evaluate the success of the system didactically by addressing these principles. Although these principles are developed according to this specific case study, it is believed that they can be improved and implemented into any web-based instructional system.

Currently we are adapting the ERRL system to curriculum of the related courses in the Electrical Engineering Program of the University by creating technology enhanced learning environments. In that context it is believed that this study will guide the instructional designers of such systems. Additionally, by establishing similar requirements analyzes, the educators may also adapt the ERRL system or other similar systems to their environments. Our preliminary results based on the created technology enhanced learning environments which is designed through the ERRL system according to the requirements of our learner groups, are promising.

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