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Developing a Conceptual Model for Establishing Virtual Laboratories

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***Abstract*— Considering the importance of technical laboratories with the purpose of research and/or training in universities and industries, virtual and remote laboratories have become an important issue for today's technological world. Despite of development of various virtual laboratories in some universities around the world, there is no rigorous model structure and/or specification checklist or standards for establishing or evaluating such laboratories. This paper presents a conceptual model and some appropriate checklist to be used for establishing and/or evaluation of virtual and remote laboratories. The checklist has been set up based on a comparison of 20 virtual laboratories around the world and also more than 10 years experiences of the authors in developing e-learning programs and virtual laboratories. The findings and recommendations of this paper could also be considered as some initial step toward standardization of virtual laboratories.**

Keywords- Conceptual Model; Virtual Laboratory; E-Learning; Key Components

I. INTRODUCTION

Recent advances in fields such as computing, communication, sensing, and software technologies have created a new environment which offers a great deal of opportunities in engineering fields to expand its contributions to the economic growth and achieving a more developed society. In the last two decades, the Internet and networks have proved to be powerful tools for both educational and distributed collaborative works [1, 2, 3, 4]. Developing e-Learning programs, virtual universities, and virtual and remote laboratories are examples of this new environment. In this paper, the focus is on virtual laboratories as technologically important and complicated parts of such developments.

Though there have been quite a large number of such virtual laboratories developed around the world [5, 6], there are neither rigorous model nor a set of clear standards for establishing a new one or evaluating the existing ones. Therefore, finding appropriate conceptual models and some essential features for such laboratories are significant steps toward standardization of such developments.

In this study, more than twenty universities across the world have been investigated and common characteristics of these laboratories were extracted. These features have been considered as the key components composing a virtual laboratory. Although each of these universities has its own methods for establishing a virtual lab, most of them have followed a series of common policies in establishing their labs. Besides, more than 10 years experiences of the authors in developing e-learning programs and virtual laboratories have been invoked. All these together have led to proposing a conceptual model and some appropriate checklist to be used for establishing and/or evaluating of virtual and remote laboratories.

II. INVESTIGATING THE AVAILABLE VIRTUAL LABORATORIES

This section provides the results of studying a number of virtual laboratories across the world in details and giving a brief description of each as examples of such laboratories. Nevertheless, a more comprehensive comparison will be presented in Section III.

A. University of Tennessee's Virtual Laboratory

This website was established in 1995 and with the effort of Jim Henry using LabVIEW software, presenting online laboratory experiment in the fields of chemical engineering, control engineering, mechanical engineering and Dynamic Processes [7].

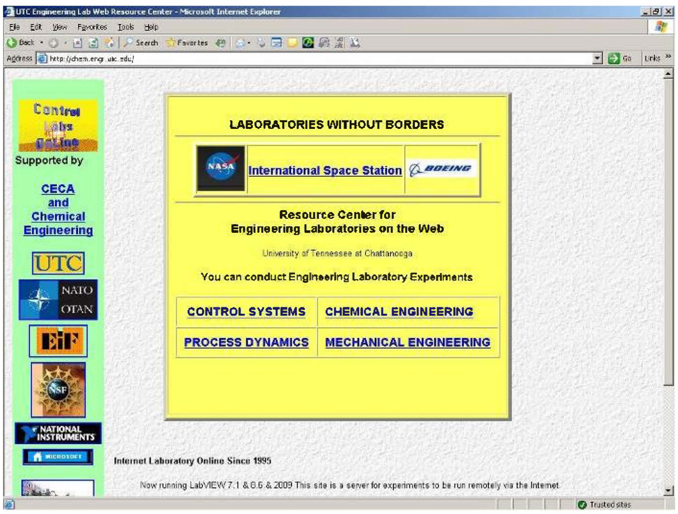

Figure 1. University of Chattanooga Virtual Laboratory [7]

The experiments presented include: voltage, temperature, velocity, water depth, current flow and pressure measurement.

B. University of Oregon's Virtual Laboratory

This website is created by University of Oregon's physics department which needs only the JAVA application to perform. The experiments presented in this website, mostly cover basic physics and science. This website includes five major sections including astrophysics, energy and environmental physics, mechanical physics and thermodynamics.

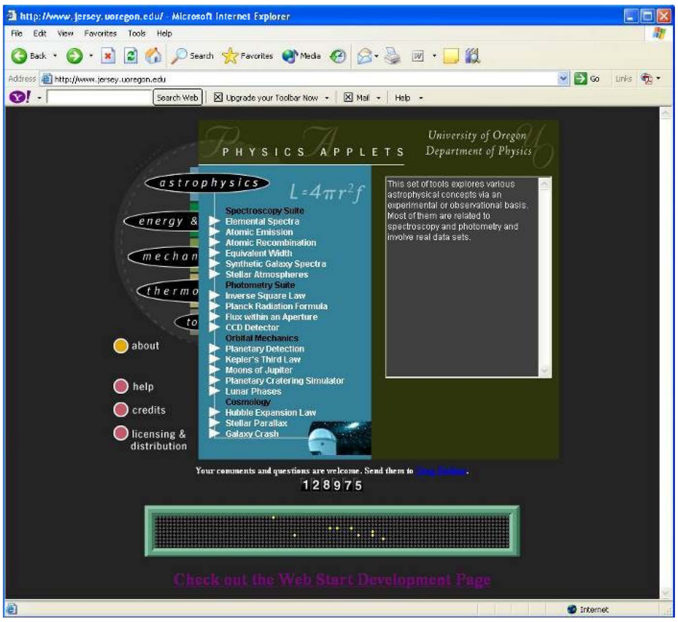

Figure 2. University of Oregon's Virtual Laboratory [8]

C. Universiy of Bochum's Virtual Laboratory

This website has been online since 1996 and the experiments are presented using graphical animations and as a result are more comprehensible by the user. In fact this laboratory is evaluated as one of the most successful and powerful examples of a virtual laboratory. In spite of all these benefits and advantages, lack of theoretical information about each experiment is a major drawback which faces the user with some difficulty running an experiment. Furthermore in order to benefit from all these tools and features, one needs to install a number of applications on his/her computer.

Figure 2. University of Bochum's Virtual Laboratory [9]

D. Johns Hopkins University's Virtual Laboratory

In this website several laboratories considering various fields are offered and are presented for students of engineering and science fields. The main software used in this website is JAVA and any version of Internet Explorer above 3.0 or Netscape above 3.01 may be used. Furthermore some of the experiments require a version of MPEG Viewer.

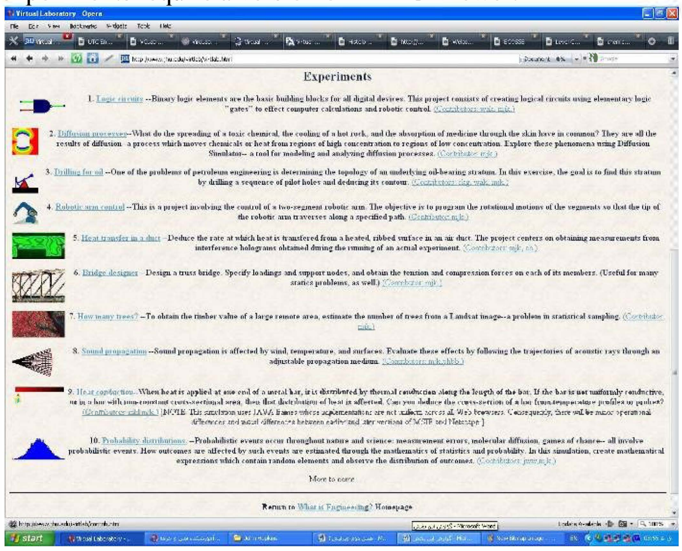

Figure 4. Johns Hopkins University's Virtual Laboratory [10]

E. ViroLab's Virtual Laboratory

This laboratory has been designed and developed by GridSpace Company in order to support virologists, epidemiologists, HIV specialists and the possibility to cure HIV positive individuals.

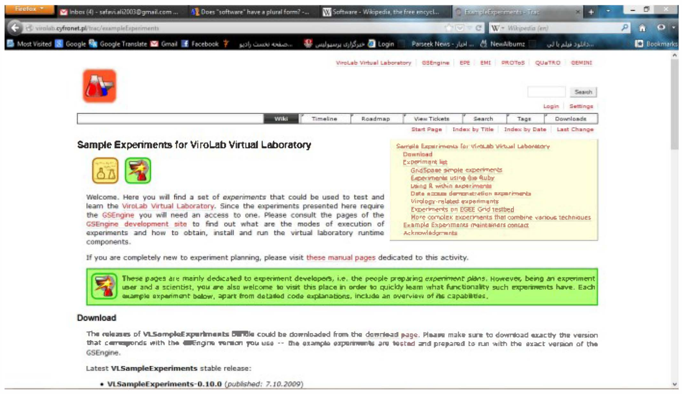

Figure 5. Virolab's Virtual Laboratory [11]

F. Virtual Labs of India

This laboratory is specially designed for bachelor students, though it also offers services to students in higher levels as well as researchers.

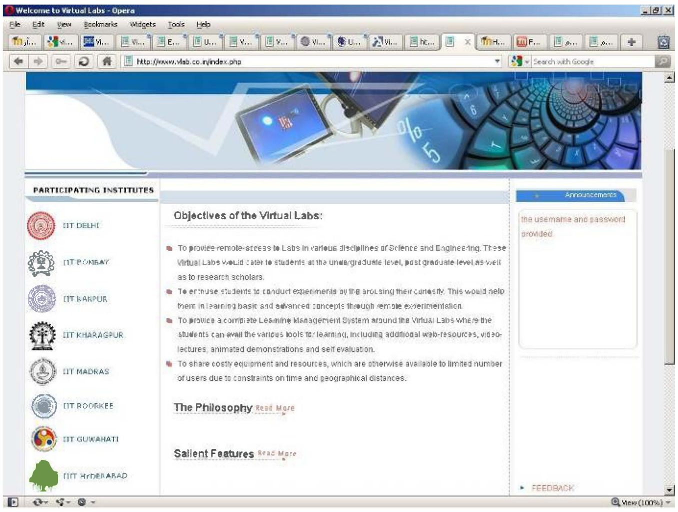

Figure6. Virtual Laboratories of India [12]

G. *Shiraz University's Virtual Laboratory*

This laboratory presents a number of advanced control virtual and remote experiments. An experiment for controlling a robot's arm is illustrated in Figure 6.

Figure 7. Shiraz University's Virtual Laboratory [14]

III. Key Components In A Virtual Laboratory

In this section and after a brief representation of a number of virtual laboratories across the world, in this part of the paper over 20 universities are compared and the key components are extracted. These components consist of: Interaction, Content, Services, Tools and Results. In the following section, each of these components will be discussed and evaluated for the considered virtual laboratories. Tables of comparison are presented, summarizing the study of each component.

A. *Interaction*

Interaction in an e-learning environment has proven to be a challenging issue, since it is far more complicated in regards to traditional leaning methods. Improper interaction techniques may result in an environment which discourages the user to continue his/her learning. As a result e-learning environments require a thoughtful and attentive design for interactive activities.

A significant matter is that in theoretical courses the course content could be put into a text file, however in virtual laboratories interaction is inevitable. In such laboratories the student has no choice but to use simulation tools in addition to other features for running an experiment and acquiring the results.

With the investigation of the virtual laboratories, interaction could be considered in three ways:

1) Tool-Based Interaction: Whenever in a designed laboratory the entire parameters, values and settings in the simulation tools are available or selectable in a way which any setting preference is accessible, or any value could be chosen for the required parameters in the experiment, the interaction's type is tool-based. An example for such interaction is Carnegie Mellon's chemistry virtual laboratory [25].

2) Data-Based Interaction: In these types of interactions, the user has to put all the required values assigned to each parameter in a text box and then push the start button. Tennessee' virtual laboratory [7] is a case for such types. In such laboratories the input is analyzed and the output is usually presented as numbers or graphs and simulation is often not used.

3) Combined Interaction: In such cases both simulation tools and input text files are applied. Alabama's virtual laboratory [15] uses such a method.

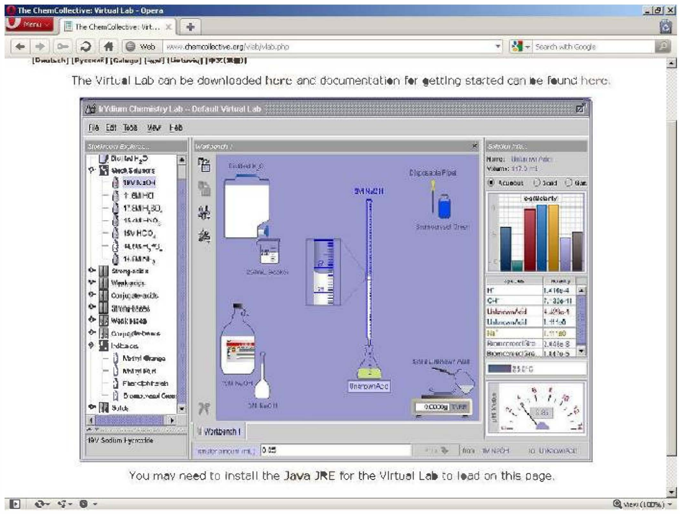

Figure 8. *Carnegie Mellon's Chemistry Virtual Laboratory* [25]

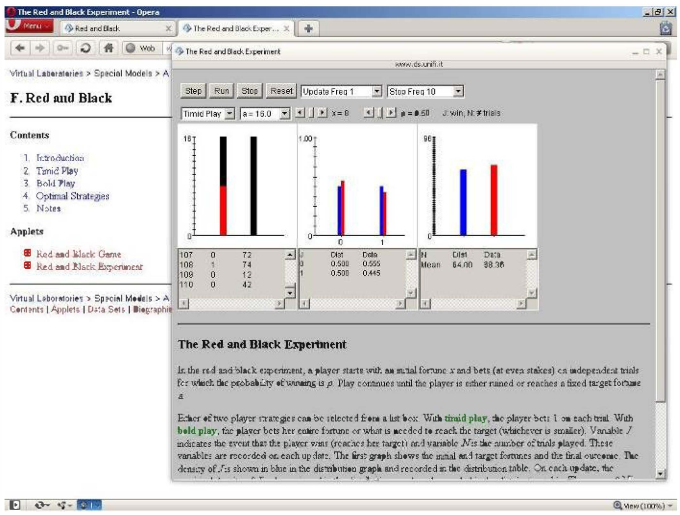

Figure 9. *Alabama's Virtual Laboratory* [15]

B. Tools

Virtual tools are often referred to as the main gears of a virtual laboratory. In a real laboratory tools are presented as hardware and physical toolkit, though in a virtual one these tools are simulated using programming languages.

In this study and regarding the tools applied in each case, the following features were extracted to evaluate a laboratory.

- The ability to support various web explorers, i.e.: AOL, Firefox, Opera, Internet Explorer, Safari
- The ability to support JAVA Applets: a popular feature used in a huge number of virtual laboratories for designing graphs and illustrating results based on the obtained data.
- Use of Flash files: a simple tool for providing content in e-learning environments.
- Use of MATLAB/Simulink: A popular software and a well-known name for engineering students
- Integration of tools: The important question here is that if the user has to search for each of the tools required for a certain experiment all over the laboratory they are already there.
- Use of both audios and videos: A method to give a better understanding in certain experiments
- Use of LabVIEW: Another popular engineering software

A Comparison between different laboratories regarding their tools' features is summarized in Table 1.

TABLE 1. COMPARISON BETWEEN LABORATORIES' TOOLS

No.	Universities	Audio and Video	Tools Integration	Usage of MATLAB and LabVIEW	Supporting Flash Players	Supporting JAVA Applet	Supporting Every Explorer
1	Alabama in Huntsville [15]	✓	✓	✓	✓	✓	✓
2	Johns Hopkins [10]	✓	✓	✓	✓	✓	✓
3	Tennessee at Chattanooga [7]	✓		✓	✓	✓	
4	National Taiwan [16]	✓	✓	✓	✓	✓	✓
5	Iowa [17]		✓		✓	✓	✓
6	EPFL [18]	✓	✓	✓	✓		✓
7	India [12]	✓		✓	✓	✓	✓
8	Arizona [19]	✓	✓		✓	✓	
9	Virolab [11]	✓	✓	✓		✓	✓
10	UNESCO [20]	✓		✓	✓		✓
11	MERLOT [21]	✓	✓	✓	✓	✓	✓
12	Monash [22]	✓			✓	✓	✓
13	California [23]	✓	✓	✓		✓	✓
14	Oxford [24]	✓	✓	✓	✓	✓	✓
15	Carnegie Mellon [25]		✓	✓		✓	✓
16	Bochum [9]	✓	✓		✓	✓	✓
17	Alabama in Huntsville [26]	✓	✓	✓	✓	✓	
18	Basel, Switzerland [27]	✓		✓	✓	✓	✓
19	Washington [28]	✓	✓	✓	✓		✓
20	Oregon [8]	✓	✓	✓	✓	✓	
21	Shiraz [14]	✓	✓		✓		✓
22	Edinburgh [29]	✓	✓	✓	✓	✓	✓
23	Utah [30]	✓	✓	✓	✓	✓	

C. Content

The same principles as in a content management system are applied here. In this paper it not aimed to discuss the principles but to simply investigate the quality of their usage in different virtual laboratories. Table 2 represents a summary of comparing various laboratories around the world regarding their content. The most important feature to evaluate a laboratory's content management are considered as following:

- Use of animations: a widely held method to attract the user
- Use of questions and answers
- Different content for each experiment instead of a single content for the entire laboratory
- Categorized content for different sections
- Content presented as a file, easily downloadable
- Theories are presented for each section

TABLE 3. COMPARISON BETWEEN LABORATORIES' CONTENT

No.	Universities	Use of Animations	Use of Questions	Different Content for Each Experiment	Categorized Content	Content Presented as a File	Theories are Presented
1	Alabama in Huntsville [15]	✓	✓	✓	✓	✓	✓
2	Johns Hopkins [10]	✓	✓	✓	✓	✓	✓
3	Tennessee at Chattanooga [7]	✓	✓	✓	✓		
4	National Taiwan [16]	✓		✓	✓	✓	✓
5	Iowa [17]		✓		✓	✓	✓
6	EPFL [18]	✓	✓	✓	✓	✓	
7	India [12]		✓			✓	✓
8	Arizona [19]	✓		✓	✓	✓	✓
9	Virolab [11]	✓	✓	✓	✓	✓	✓
10	UNESCO [20]	✓	✓	✓		✓	✓
11	MERLOT [21]		✓	✓	✓	✓	
12	Monash [22]	✓	✓		✓	✓	✓

13	California [23]		✓	✓		✓	✓
14	Oxford [24]	✓		✓	✓	✓	
15	Carnegie Mellon [25]	✓	✓			✓	✓
16	Bochum [9]	✓	✓	✓	✓	✓	
17	Alabama in Huntsville [26]		✓		✓	✓	✓
18	Basel, Switzerland [27]	✓		✓	✓	✓	✓
19	Washington [28]	✓	✓	✓	✓	✓	✓
20	Oregon [8]	✓	✓	✓	✓		✓
21	Shiraz [14]	✓	✓	✓	✓	✓	
22	Edinburgh [29]	✓	✓	✓	✓	✓	✓
23	Utah [30]	✓	✓	✓	✓	✓	

D. Services

For a more realistic experiment, proper services are essential. The following services have been obtained through studies:

- Membership Registration: The user needs to enter his/her identity information such as username, password, mail address, etc., for the system to offer its services.
- Help Information: In every laboratory there are tools and objects which proper guidance must be given about them for an appropriate experiment.
- Implementation and Demonstration Procedure: studies show that these procedure could be categorized in three main categories: Basic Demonstration (simple representation, usually numbers only, i.e. [17]), View Demonstration (Using software such as MATLAB a more understandable two or even three dimensional view of the experiment is presented i.e. [22]), Full Demonstration (Using decent simulation techniques to make it as realistic as possible i.e. [23]).
- Offering Source Codes for Different Experiments: to be used in other virtual laboratories
- Providing the Prerequisite for The Experiment

The summarized results of comparing different universities is presented in Table 3.

TABLE 3. COMPARISON BETWEEN LABORATORIES' SERVICES

No.	Universities	Providing the Prerequisite for The Experiment	Program's source codes availability	Implementation and demonstration procedure	Guidance information	Membership
1	Alabama in Huntsville [15]	✓	✓		✓	
2	Johns Hopkins [10]		✓	✓	✓	✓
3	Tennessee at Chattanooga [7]	✓		✓		✓
4	National Taiwan [16]	✓	✓	✓	✓	
5	Iowa [17]	✓		✓	✓	✓
6	EPFL [18]	✓	✓		✓	
7	India [12]	✓		✓	✓	
8	Arizona [19]	✓	✓	✓	✓	✓
9	Virolab [11]	✓		✓	✓	
10	UNESCO [20]		✓	✓	✓	✓
11	MERLOT [21]	✓	✓		✓	✓
12	Monash [22]		✓	✓	✓	✓
13	California [23]		✓	✓		✓
14	Oxford [24]	✓	✓	✓	✓	✓
15	Carnegie Mellon [25]	✓	✓		✓	✓
16	Bochum [9]	✓	✓	✓	✓	✓
17	Alabama in Huntsville [26]	✓	✓		✓	✓
18	Basel, Switzerland [27]	✓	✓	✓	✓	
19	Washington [28]		✓		✓	✓
20	Oregon [8]		✓	✓	✓	
21	Shiraz [14]	✓	✓	✓		✓
22	Edinburgh [29]	✓	✓	✓	✓	✓
23	Utah [30]	✓	✓		✓	✓

E. Results

An important component which discriminates different laboratories is the quality of their result's demonstration. Different types of outputs have been considered and various universities have been evaluated using them. Table 4 illustrates the summary of this part of the research.

TABLE 4. COMPARISON BETWEEN LABORATORIES' RESULTS

No.	Universities	Availability of Dara as an Excel or a Text File	Data Could be Saved On the System	Results are Shown To User	Results are Presented as Graphs	Results are Shown as Numbers
1	Alabama in Huntsville [15]	✓	✓	✓	✓	✓
2	Johns Hopkins [10]	✓	✓	✓	✓	✓
3	Tennessee at Chattanooga [7]		✓	✓	✓	
4	National Taiwan [16]	✓	✓	✓	✓	✓
5	Iowa [17]	✓		✓	✓	✓
6	EPFL [18]	✓	✓	✓		✓
7	India [12]		✓	✓	✓	✓
8	Arizona [19]	✓		✓	✓	
9	Virolab [11]	✓	✓		✓	✓
10	UNESCO [20]		✓	✓		✓
11	MERLOT [21]	✓	✓	✓	✓	✓
12	Monash [22]			✓	✓	✓

13	California [23]	✓	✓		✓	✓
14	Oxford [24]	✓	✓	✓	✓	✓
15	Carnegie Mellon [25]	✓	✓		✓	✓
16	Bochum [9]	✓		✓	✓	✓
17	Alabama in Huntsville [26]	✓	✓	✓	✓	
18	Basel, Switzerland [27]		✓	✓	✓	✓
19	Washington [28]	✓	✓	✓		✓
20	Oregon [8]	✓	✓	✓	✓	
21	Shiraz [14]	✓		✓		✓
22	Edinburgh [29]	✓	✓	✓	✓	✓
23	Utah [30]	✓	✓	✓	✓	

IV. DEVELOPING A CONCEPTUAL MODEL

At this point, after studying the available virtual laboratories, a conceptual model was developed for an effective and reasonably acceptable virtual laboratory, as it is seen in Figure 10. For each of these components, a checklist has been proposed. As seen in the figure, the study reveals that interaction plays the main role and has the most important effect, influencing all other factors in establishing a successful virtual laboratory. The significance of such a factor is as much seeming that other components relate to the main purpose through interaction. Thus, the presented model may also be called the "Interaction Model". Using this model, Tables 5 to 9 are presented, proposing a number of checklists to evaluate different virtual laboratories' components for a more decent assessment.

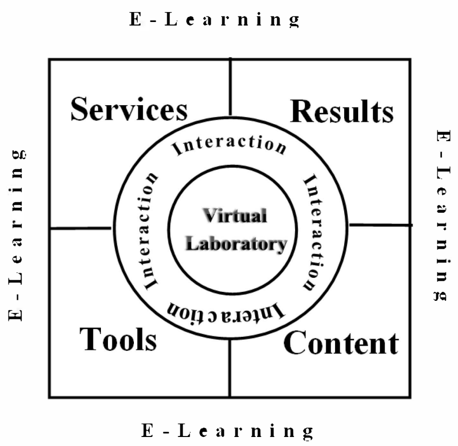

Figure 10. Structure of our proposed model

TABLE 5. INTERACTION EVALUATION CHECKLIST

Grade A= excellent / B=good / C=average /D=weak	
1. Proper interaction's anticipation and design	A B C D
2. Student has an effective interaction with the lab	A B C D
3. Student interacts with other students	A B C D
4. The instructor interacts with the students for guidance	A B C D
5. How much simulation has been used for interacting	A B C D
6. How much of the interaction is data-driven	A B C D
7. Amount of the interaction during the experiment which is up to the student	A B C D
8. Virtual machine's interactive operations speed during the experiments	A B C D

TABLE 6. TOOLS EVALUATION CHECKLIST

Grade A= excellent / B=good / C=average /D=weak	
1. Does the laboratory support all Internet explorers?	A B C D
2. Proper tools have been used for designing the website layout	A B C D
3. Does it support Java Applet?	A B C D
4. Does it use Flash files?	A B C D
5. Does it use MATLAB/Simulink?	A B C D
6. Does it use LabVIEW?	A B C D
7. Integration of tools	A B C D
8. Amount of the audio/video files used	A B C D

TABLE 7. CONTENT EVALUATION CHECKLIST

Grade A= excellent / B=good / C=average /D=weak	
1. Theoretical contents are provided for the experiments	A B C D
2. The theoretical contents for each experiment is provided as a file for the user	A B C D
3. Categorized content for different sections and experiments	A B C D
4. For each experiment a different content is presented	A B C D
5. Questions and answers are presented	A B C D
6. Animation has been used for theoretical foundation of each experiment	A B C D
7. Congruity between contents and experiments	A B C D
8. Proportion between the amount of content and the experiment runtime	A B C D

TABLE 8. SERVICE EVALUATION CHECKLIST

Grade A= excellent / B=good / C=average /D=weak	
1. Membership	A B C D
2. Help Information	A B C D
3. Demonstrating and implementing procedure	A B C D
4. Presenting source codes	A B C D
5. Providing prerequisites for experiments	A B C D
6. Sending necessary information via e-mail	A B C D
7. Different types of accounts for students and instructors	A B C D
8. Timetable for presenting real-time experiments	A B C D

TABLE 9. RESULTS EVALUATION CHECKLIST

Grade A= excellent / B=good / C=average /D=weak	
1. Results represented by numbers	A B C D
2. Results represented by graphs	A B C D
3. Data is represented to the user	A B C D
4. Data is saved on the system	A B C D
5. Data is saved as a text file	A B C D
6. Data is saved as an Excel file	A B C D
7. Data is downloadable for the user	A B C D

8. Experiments are send to both instructor and student in an reasonable amount of time	A B C D

V. CONCLUSION

Through studying over twenty universities across the world and invoking the 10 years experiences of the authors in developing e-learning programs and virtual laboratories, five components were extracted as the main factors consisting a virtual laboratory which are: Interaction, Content, Services, Tools, and Results. Lack of proper contemplation towards any of the mentioned components may cause serious challenges and shortcomings. As a result of these components and the comparison between the mentioned laboratories a conceptual model was developed and proposed, which may eliminate any chance of inadvertence towards considering the role of influential components. The proposed model facilitates establishing a new virtual laboratory and prevents confusion in presenting one.

This study explicates the following points which are believed to be quite important for establishing a new laboratory:

- A number of laboratories were abandoned halfway through as a result of not considering the key components (i.e. A huge number of Indian universities had such a problem).
- Considering the important features of a real laboratory when developing a virtual laboratory is quite important. (i.e. Carnegie Mellon [25]).
- Before establishing a virtual laboratory it is quite important to consider how much of the components could be forged, if not all, better stop before wasting any time or money!
- It is suggested that before establishing a complete virtual laboratory, finish a single experiment successfully and start by developing it.
- It is suggested that before establishing a virtual laboratory, hardware and software infrastructures are well thought out.

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