Educational Objectives Of Different Laboratory Types:  
A Comparative Study

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Abstract— Lab courses play a critical role in scientific education. Modern technology is changing the nature of the laboratories, and there is a great comparison between hands-on, simulated and remote laboratories. The remote lab technology has brought a significant improvement in communication within the Academic community and has improved students' learning experiences. There are different educational objectives as criteria for judging the laboratories: Hands-on labs increase the Ability to design and investigate (design skills), while remote labs focus on conceptual understanding. Remote laboratories offer all the advantages of the new technology, but are often a poor replacement for real laboratory work. Remote laboratories are similar to simulation techniques in that they require minimal space and time, because the experiments can be rapidly configured and run over the Internet [Web]. But unlike simulations, they provide real data. This paper presents a comparative analysis for the educational objectives of the three laboratory techniques; hands-on, simulated, and remote laboratories. In addition, it proposes enhancements for the remote lab activities leading to improving its performance.

Keywords- Hands-on laboratory, Remote laboratory, Virtual laboratory, distance learning, E-learning.

I. INTRODUCTION

Different educational objectives are used as criteria for judging the laboratories: Hands-on advocates emphasize design skills, while remote lab advocates focus on conceptual understanding. Nersessian [1991] goes so far as to claim that “hands-on experience is at the heart of science learning” and Clough [2002] declares that laboratory experiences “make science come alive.” Lab courses have a strong impact on students’ learning outcomes, according to Magin et al. [1986].

This domain of study ranges across many disciplines, and is challenging to survey. In order to find the existing literature, we focused on three electronic databases: ACM, IEEE, and Science Direct. As a result, 60 articles were selected for a full-text review and coding (20 publications for each; hands-on labs, simulated labs, and remote labs). These articles are listed in the Appendix.

Most of the literature focuses on engineering laboratories as the engineering discipline contains the biggest portion of laboratory studies. Engineering professors may also see the labs as connected to future employment [Faucher 1985]. In other words, engineering is an applied science. Alternatively, the impetus for the creation of a remote laboratory may come from an engineer’s desire to build something. This paper presents a comparative analysis for the educational objectives of the three laboratory techniques; hands-on, simulated, and remote laboratories. In addition, it proposes enhancements for the remote lab activities leading to improving its performance.

The rest of this paper is organized as follows: Section II introduces Comparison of Different Laboratory Types. Section III introduces analysis and discussion of the educational Objectives. Section IV presents our conclusion. Finally, section V concludes our Recommendations for enhancing the performance of remote laboratories.

II. COMPARISON OF DIFFERENT LABORATORY TYPES

The three types of labs are sometimes compared to each other, while in other cases the labs are merged. The integrated teaching and learning (ITL) program at the University of Colorado at Boulder provided an example of how to combine hands-on practice with simulation experience and remote experimentation [Schwartz and Dunkin 2000]. A handful of articles evaluated remote laboratories in comparison to hands-on laboratories [Sicker et al. 2005] or simulated laboratories in comparison to hands-on laboratories [Engum et al. 2003]. Engum et al. [2003] showed that hands-on labs were more effective than simulated.
A summarized description of the three types of labs is described below.

- **Hands-On Labs**: Hands-on labs involve a physically real investigation process. Two characteristics distinguish hands-on from the other two labs: (1) All the equipment required to perform the laboratory is physically set up; and (2) the students who perform the laboratory are physically present in the lab. On the other hand, hands-on experiments are seen as too costly. Hands-on labs put a high demand on space, instructor time, and experimental infrastructure, all of which are subject to rising costs [Farrington et al. 1994]. Also, due to the limitation of space and resources, hands-on labs are unable to meet some of the special needs of disabled students [Colwell et al. 2002] and distant users [Watt et al. 2002]. Additionally, students’ assessments suggest that students are not satisfied with current hands-on labs [Dobson et al. 1995].

- **Simulated Labs**: Simulated labs are the imitations of real experiments. All the infrastructure required for laboratories is not real, but simulated on computers. Some note that the cost of simulation is not necessarily lower than that of real labs [Canizares and Faur 1997]. Realistic simulations take a large amount of time and expense to develop and still may fail to faithfully model reality [Papathanassiou et al. 1999]. The theory of situated learning (e.g., McLellan [1995]) would suggest that what students learn from simulations is primarily how to run simulations.

- **Remote Labs**: Remote labs are characterized by mediated reality. Similar to hands-on labs, they require space and devices. What makes them different from real labs is the distance between the experiment and the experimenter. In real labs, the equipment might be mediated through computer control, but colocated. By contrast, in remote labs experimenters obtain data by controlling geographically detached equipment.

In other words, Reality in remote labs is mediated by distance. Remote labs are becoming more popular [Yoo and Hovis 2004]. They have the potential to provide affordable real experimental data through sharing experimental devices with a pool of schools [Sonnenwald et al. 2003]. Also, a remote lab can extend the capability of a conventional laboratory. Along one dimension, its flexibility increases the number of times and places a student can perform experiments [Canfora et al. 2004].

Along another, its availability is extended to more students [Cooper et al. 2002b]. Additionally, comparative studies show that students are motivated and willing to work in remote labs [Cooper et al. 2002b]. Some students even think remote labs are more effective than working with simulators [Scanlon et al. 2004].

### III. Analysis and Discussion of the Educational Objectives

In order to study this hypothesis, first, the articles (in the appendix) are coded based on educational objectives. A four-dimensional goal model is developed for laboratory education (see Table I). This model is built starting with the educational goals proposed by the Accreditation Board for Engineering and Technology (ABET) [2005].

| Lab Goals          | Description                                                                 | Goals from ABET                                                                 |
|--------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Conceptual understanding | Extent to which laboratory activities help students understand and solve problems related to key concepts taught in the classroom. | Illustrate concepts and principles.                                               |
| Design skills      | Extent to which laboratory activities increase student’s ability to solve open-ended problems through the design and construction of new artifacts or processes. | Ability to design and investigate.                                               |
| Social skills      | Extent to which students learn how to productively perform engineering-related activities in groups. | Understand the nature of science (Scientific mind).                              |
| Professional skills | Extent to which students become familiar with the technical skills they will be expected to have when practicing in the profession. | Social skills and other productive team behaviors (communication, team interaction and problem solving, leadership). |

Figures 1, 2 and 3 shows the educational goals for each lab summarized from the articles reviewed.

![Educational Goals for Hands-on Lab](image-url)
Our research will contribute in enhancing both social and design skills by augmenting the remotely accessed lab with the second life.

Second Life (SL) is a virtual world developed by Linden Lab launched on June 23, 2003 and is accessible via the Internet. A free client program called the Second Life Viewer enables its users, called Residents, to interact with each other through avatars. Residents can explore, meet other residents, socialize, participate in individual and group activities, and create and trade virtual property and services with one another, or travel throughout the world, which residents refer to as the grid. [26]

The results from this sample of articles suggest the following possible explanation for the debate over laboratories. Adherents of hands-on laboratories find other laboratories to be lacking. They do not believe that alternative labs can be used in teaching design skills. By contrast, adherents of remote laboratories think the hands-on laboratory researchers are ignoring evidence which shows that remote laboratories are effective in teaching concepts. Remote laboratory adherents are evaluating their own efforts with respect to teaching concepts, not design skills.

On the other hand, researchers are confounding many different factors, and perhaps over-attributing learning success to the technologies used. There is much in the literature to suggest that both students’ preferences and learning outcomes are the result of many intertwined factors. Thus, it is sensible to suggest that researchers more carefully isolate and study the different factors which might interact with laboratory technology in determining educational effectiveness. However, such work is difficult. It is hard to perform large-scale educational tests and hold factors such as instructor ability constant. It is also difficult to compare studies which focus on different scientific domains. Thus, it is especially important that effort should be focused on areas that look the most promising.

- First, research may look at hybrids of laboratories that are designed to accomplish a portfolio of educational objectives. There is a fair amount of evidence that simulated and remote labs are effective in teaching concepts.
- Second, the effectiveness of laboratories may be affected by how much students believe in them. Therefore, an understanding of presence, interaction, and belief may lead to better interfaces.
- Third, research might pay more attention to collaboration and sense making. The technology may change the way we can and should coordinate our work.

The main advantages and disadvantages of each type of laboratory according to some features are summarized in Table II.
Table II. Comparative list of advantages and disadvantages of Real, Virtual and Remote laboratories.

| Feature          | Hands-on Labs | Simulated Labs | Remote Labs               |
|------------------|---------------|----------------|---------------------------|
| **Access Mode**  | Adv. | Adv. | Adv. |                   |
| Physical access  | Virtual access to experiments using simulation programs. | Using the internet and SW to access the lab remotely. |                                      |
| to lab.          |                   |                |                          |
| • Realistic data. | • Good for concept validation. | • No time and space restrictions. |                                      |
| • Interaction with real equipment. | • No time and physical restrictions. | • Realistic data. |                                      |
| • Open ended experiments are possible. | • Feeling of reality. |                   |                                      |
| **Infrastructure** | Disadv. | Disadv. | Disadv. |                   |
| HW components and computers if required. | Simulation SW programs. | Hardware components, computers and communication media. |                                      |
| Adv. | Adv. | Adv. |                   |
| • Offer students the sense of the reality. | • Good for conceptual understanding. | • Offer students to make the experiment more times. |                                      |
| • Help students to connect the experiment under staff supervision. | • Secure if safety precautions are taken into account. | • Useful if more real results are required. |                                      |
| **Pedagogical** | Disadv. | Disadv. | Disadv. |                   |
| HW components, computers and communication media. | Finite lifetime of the HW components. | Finite lifetime of the HW components. |                                      |
| Adv. | Adv. | Adv. |                   |
| • Finite lifetime of the HW components. | Need SW update. | Need SW update. |                                      |
| • Needs maintenance of the HW components. |                   |                  |                                      |
| • Vulnerable to damage (misuse, theft,……). |                   |                  |                                      |
| **Economical** | Adv. | Adv. | Adv. |                   |
| Physical access to lab. | Virtual access to experiments using simulation programs. | Using the internet and SW to access the lab remotely. |                                      |
| Adv. | Adv. | Adv. |                   |
| • Students may not complete experiments in lab period. | Supervision of academic staff not available. | Need enhancing in both social and design skills. |                                      |
| • Supervision required. | No sense with real equipment of the experiment. |                   |                                      |
| **Expensive** | Low cost | Medium cost if reduces the number of used labs. | | (Disadv.) |

IV. CONCLUSION

We found that most of the articles discussing the educational objectives of different laboratory types were engineering-related. Additionally, there were advocates and detractors for each different type of laboratory. We asked what might explain the continued unresolved debate. The debate can be partially explained by examining the educational objectives associated with each laboratory type. Hands-on lab adherents emphasize the acquisition of design skills as an important educational goal, while remote laboratory adherents do not evaluate their own technology with respect to this objective.

In conclusion, there is no simple answer to the question, which laboratory is the best for engineering students? All types of laboratories offer certain advantages. We believe that engineering students should be offered through the duration of their programs a balanced mixture of real, virtual and remote labs.

This paper provides a starting place for researchers involved in the discussion about the role and value of laboratory work. Perhaps a sense of reality can be achieved by students not only in hands-on experience, but also in virtual environments. It is sure with the proper mix of technologies we can find solutions that meet the economic constraints of laboratories by using simulations and remote labs to reinforce conceptual understanding, while at the same time providing enough open-ended interaction to teach design. Our review suggests that there
is room for research that seeks to create such a mix, which might be informed by studies of coordination as well as the interactions that lead students to a sense of immersion.

V. RECOMMENDATIONS FOR ENHANCING THE PERFORMANCE OF REMOTE LABS

- Improving social skills through constructing distributed remote labs.
- Improving design skills through constructing remote labs for the applications which basically depend on computers in real labs such as FPGA labs and other related labs.
- Development of Augmented Reality Labs. Augmented Reality Laboratories (ARLs) Combined Remote Lab Access with Second Life. Adobe Conferencing system with Webcam for lab visualization through the Web in Second life.

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**APPENDIX**

I. TABLES OF EDUCATIONAL OBJECTIVES AND ARTICLES

| Acc.&Flex.: Accessibility & Flexibility | Phy: Physiology |
|----------------------------------------|----------------|
| Art.: Article                          | Subject (sub.) |
| AE: Aeronautical Engineering           | ME: Mechanical Engineering P: Physic |
| B: Biology                             | MME: Mechanical and Manufacturing Engineering |
| CE: Chemical Engineering               | C.U.: Conceptual Understanding D.S.: Design Skills |
| Clm: Climatology                      | C.U. |
| CS: Computer Science                   | C.U. |
| CVE: Civil Engineering                 | C.U. |
| EE: Electrical Engineering             | C.U. |
| EES: Environmental and ecological science | C.U. |
| INS: Interdisciplinary IS: Internet Science | C.U. |
| Objectives                             | C.U. |

**Table IV. Simulated Laboratory Article Objectives**

| Art. | Sub. | Meth. | Constraints | Educational Objectives |
|------|------|-------|-------------|------------------------|
|      |      |       | Time & Cost | Acc. & Flex. | C.U. | P.S. | D.S. | S.S. |
| [1]  | EE   | T     | √           | √           | √    | √    | √    | √    |
| [2]  | TE   | T     | √           | √           | √    | √    | √    | √    |
| [3]  | EE   | T     | √           | √           | √    | √    | √    | √    |
| [4]  | EE   | T     | √           | √           | √    | √    | √    | √    |
| [5]  | ME   | T     | √           | √           | √    | √    | √    | √    |
| [6]  | EE   | Q     | √           | √           | √    | √    | √    | √    |
| [7]  | CE   | T     | √           | √           | √    | √    | √    | √    |
| [8]  | ME   | Q     | √           | √           | √    | √    | √    | √    |
| [9]  | ME   | Q     | √           | √           | √    | √    | √    | √    |
| [10] | Phi  | Q     | √           | √           | √    | √    | √    | √    |
| [11] | ME   | Q     | √           | √           | √    | √    | √    | √    |
| [12] | INS  | T     | √           | √           | √    | √    | √    | √    |
| [13] | CE   | T     | √           | √           | √    | √    | √    | √    |
| [14] | B    | T     | √           | √           | √    | √    | √    | √    |
| [15] | Clm  | Q     | √           | √           | √    | √    | √    | √    |
| [16] | CVE  | T     | √           | √           | √    | √    | √    | √    |
| [17] | ME   | T     | √           | √           | √    | √    | √    | √    |
| [18] | PE   | T     | √           | √           | √    | √    | √    | √    |
| [19] | PE   | T     | √           | √           | √    | √    | √    | √    |
| [20] | PE   | T     | √           | √           | √    | √    | √    | √    |
| SUM  |      |       | 13 11 20 16 9 5 |

**Table V. Remote Laboratory Article Objectives**

| Art. | Sub. | Meth. | Constraints | Educational Objectives |
|------|------|-------|-------------|------------------------|
|      |      |       | Time & Cost | Acc. & Flex. | C.U. | P.S. | D.S. | S.S. |
| [1]  | ME   | Q     | √           | √           | √    | √    | √    | √    |
| [2]  | ME   | Q     | √           | √           | √    | √    | √    | √    |
| [3]  | ME   | E     | √           | √           | √    | √    | √    | √    |
| [4]  | ME   | Q     | √           | √           | √    | √    | √    | √    |
| [5]  | EE   | Q     | √           | √           | √    | √    | √    | √    |
| [6]  | MME  | Q     | √           | √           | √    | √    | √    | √    |
| [7]  | ME   | E     | √           | √           | √    | √    | √    | √    |
| [8]  | SE   | Q     | √           | √           | √    | √    | √    | √    |
| [9]  | CE   | E     | √           | √           | √    | √    | √    | √    |
| [10] | B    | Q     | √           | √           | √    | √    | √    | √    |
| [11] | EE   | Q     | √           | √           | √    | √    | √    | √    |
| [12] | EE   | Q     | √           | √           | √    | √    | √    | √    |
| [13] | CE   | Q     | √           | √           | √    | √    | √    | √    |
| [14] | P    | Q/T   | √           | √           | √    | √    | √    | √    |
| [15] | CE   | Q     | √           | √           | √    | √    | √    | √    |
| [16] | P    | Q     | √           | √           | √    | √    | √    | √    |
| [17] | AE   | Q     | √           | √           | √    | √    | √    | √    |
| [18] | EES  | Q     | √           | √           | √    | √    | √    | √    |
| [19] | CE   | Q     | √           | √           | √    | √    | √    | √    |
| [20] | ME   | Q     | √           | √           | √    | √    | √    | √    |
| SUM  |      |       | 6  2 20 15 13 8 |
II. ARTICLES ON HANDS-ON LABS

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