Full Paper

Abstract

As a consequence of the increased use of Internet-enabled education, there has been recent interest in whether engineering laboratories can be effectively provided in an on-line learning environment. While many people have opinions on this matter, these are often very subjective. This work uses a well-regarded set of thirteen learning objectives for engineering laboratories (from a 2002 workshop by the US Accreditation Board for Engineering and Technology) as a framework for analysing the effectiveness of virtual engineering laboratories. The analysis shows that, with a few exceptions in the areas of psychomotor skills and sensory awareness, virtual laboratories can adequately satisfy the learning objectives. It is also shown that these objectives should be explicitly considered when designing both virtual laboratory systems, and the experiments that use these systems.

Key words:

Distance Education, Laboratories, Virtual Laboratory, Virtual lab, Engineering Education

Introduction

The field of engineering is characterized by the manipulation of matter, energy and information in order to create products and services, and engineering education needs to develop effective design and analysis skills to support these goals (Feisel & Rosa, 2005). Engineering education combines theoretical knowledge imparted through lectures and tutorials with practical design skills provided during hands-on laboratory sessions (Chan & Fok, 2009). One approach to addressing these issues has been the increasing popularity and utilisation of virtual laboratories or simulations. Instead of interacting with a real physical system, students interact with a simulated model of reality. Interaction with real laboratory equipment and apparatus etches so firmly on the mind of the student that it's arguable, in the context of deeper learning; there can be no substitute (Lindsay, Liu, Murray, Lowe & Bright 2007).

There is substantial debate about the relative utility and benefits of physical laboratories and virtual laboratories. Authors have used a variety of parameters to compare the two including learning outcomes (Chan & Fok, 2009); pre-requisite resources (Budhu, 2002); and laboratory teaching goals (de Jong, Linn & Zacharia, 2013).

In this paper, our goal is to evaluate the effectiveness of virtual laboratories using a widely agreed set of learning objectives for laboratories. The most comprehensive evaluation criteria for judging the benefits of laboratories for engineering education was formulated by ABET (Accreditation Board for Engineering and Technology, in the USA) following a workshop in in 2002 (Feisel & Rosa, 2005). Thirteen learning objectives for engineering laboratories were developed during the workshop. Those objectives can be summarised as Instrumentation, Models, Experimental Design, Data Analysis, and Design, Learning from Failure, Creativity, Psychomotor Skills, Safety, Communication, Teamwork, Ethics, and Sensory Awareness. Therefore, this study analyses the effectiveness of virtual laboratories with respect to each of the 13 learning objectives.

This study includes a literature review intended to identify the effectiveness of virtual laboratories against the thirteen learning objectives outlined by ABET. The role of virtual laboratories in enhancing the learning processes of engineering students have been investigated using secondary data sources such as books, journal articles and conference proceedings. In addition, our own analysis has been added, especially where the literature is sparse.

The scope of the analysis has been restricted primarily to our own disciplines of electrical, electronic and computer engineering, and there is also some contribution from the literature on mechanical engineering. Our analysis has not considered other disciplines in detail, such as chemical, environmental, mining or materials engineering, although many of the insights will also have application there.

Different types of Engineering Laboratories

Physical Laboratories

Physical laboratories are characterized by two distinct features; (1) all the equipment involved in the experiment is present as a physical setup, and (2) the students who perform the experiment are also physically present at the same location. The students are able to manipulate the equipment and gain hands on experience on real physical artefacts.

Virtual Laboratories

In this study, the definition of virtual laboratories includes both simulation laboratories and remote laboratories.

Simulation Laboratories

Simulation reflects the imitation of real laboratories through software. All the equipment and instruments are simulated with interfaces and results displayed on a computer screen which may be cartoon-like or realistic. The mathematical equations derived from real physical phenomena drive these virtual simulations.

Remote Laboratories

Remote laboratories are similar to hands-on laboratories as they require the real devices and space; but the experiment setup and the experimenter are geographically dislocated. The experimenter submits requests for an experiment through a web interface, and the requested experiment is carried out by robotic control of the physical equipment.

ABET Learning Objectives for Laboratories

In order to analyse the effectiveness of physical laboratories some benchmark is necessary which should reflect the competencies of engineers developed in laboratory settings. As mentioned above, ABET used a workshop in 2002 to publish 13 learning objectives which served as guidelines for understanding the purpose of traditional engineering educational laboratories and which we can now use as benchmark criteria for the new virtual laboratories. According to (Bright G, D K Liu, D B Lowe C, Lindsay D & S Murray 2008) Remote and virtual laboratories are increasingly prevalent alternatives to the face to face laboratory experience, however the question of their learning outcomes is yet to be fully investigated. There are many presumptions regarding the effectiveness of these approaches; foremost amongst these assumptions is that the experience must be “real” to be effective.
Following is the definition of each objective along with our comparative analysis of each of them as they apply to virtual laboratories:

Instrumentation

Instrumentation refers to the application of appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities (Feisel & Rosa, 2005). Students need to be aware of what instruments should be used to measure which physical quantity, and how to use those instruments effectively and accurately.

In physical electronics laboratories, various instruments are used to measure physical quantities including AC and DC Voltmeters, Ohmmeters, Ammeter, Oscilloscopes, Spectrum Analysers, and Logic Analysers. However, many of these instruments are already PC-based and are controlled using mouse, keyboard and other peripheral devices. In virtual laboratories, these instruments are replaced by computer software that represents the design of the instrument at the block diagram level, enabling the student to see the structure of the instrument and examine its different features. Often in modern physical laboratories, the devices are controlled by automated or networked instruments connected to data collection software such as LabView which ultimately blurs the boundaries between physical and virtual laboratories.

Further, a study conducted by Parten (2003) revealed that virtual instruments provide students with an opportunity to analyse the instrument in more complete detail down to the circuit schematic level as compared to only the anatomic appearance visible in the physical laboratories. Further, the functional diagram of the instrument is also available to provide a better understanding of how the instrument actually works. An empirical study reveals that students working in simulation-based laboratories tend to spend longer fixation time on the screen focusing on the equipment and experiments (Education Business Weekly, 2015); which reflects their deeper cognitive activities related to instruments and equipment. However, the initial learning curve for virtual laboratories is usually shallower compared to physical laboratories (Chan & Fok, 2009); therefore, the student's familiarity with real physical instruments may be discouraged.

Models

The second objective of laboratories is to enable the students to identify the strengths and limitations of theoretical models (Feisel & Rosa, 2005). Basically, engineering models include conceptual models to develop better understanding, mathematical models to quantify the factors and graphical models to visualize the actual effects of the factors. Therefore, the aim of using laboratories is to test the physical reality of the theoretical and mathematical models.

Simulations are based on the implementation of real physical models on computers by employing programming techniques. The mathematical equations derived from real physical phenomena run the virtual simulations (Feisel & Rosa, 2005). Usually they are programmed to be as close to reality as possible but they are often criticized for being unrealistic and too rigid (Lampi, 2013). This issue can be resolved using interactive screens where the images presented on the screen are taken from a real experiment, recorded as it was being performed. The changes made in the physical quantities using mouse or keyboard can be seen as the real-time physical changes made on the screen (Hatherly, Jordan and Cayless, 2009). Thus, interactive screen simulations allow students to observe the real physical changes on the screen that would take place in physical laboratories. Further, remote laboratories also play a substantial role in observing the models as the PCs in the laboratories are connected to real equipmens in geographically detached locations; and these operations taking place in the remote location can be observed on the computer screen (Elawady & Tolba, 2009). Perceptual psychology provides an abundance of phenomena, ranging from amodal completion to picture perception, that indicate thatphenomenal realness is an independent perceptual attribute that can be conferred to perceptual objects in different degrees (Rainer M , 2013).

Nevertheless, the virtual laboratories have the advantage of making possible the evaluation of models that are impossible to experience physically such as the effect of gravity in the space, lines of magnetic field and beams of electrons (Lang, 2012).

Experimental Design

The ability to devise a experimental approach, specify appropriate equipment and interpret the result refers to Experimental Design (Feisel & Rosa, 2005). The learning process of engineers is based on cognitive activities such as orientation, hypothesis generation, experimenting, and hypothesis testing and reaching a conclusion. Learning experimentation is significant for engineers as it leads to expertise in problem solving and critical analysis (Williams, 2012).

There is no fundamental difference in the performance of experiments and the learning process in virtual laboratories as compared to physical laboratories. However, virtual laboratories increase the speed of this process as they increase the degree of flexibility in design, observation and enable the collection of instant results (Hatherly, Jordan and Cayless, 2009). Such immediate feedback allow the students to make adjustments in the theoretical models and help create active learning environment to evaluate the error more quickly (Urdaneta & Garrick, 2012). The virtual learning environment that we developed favored the collaborative interaction between the studied students (we found that 78% of the solutions posted in the chat were initially debated among the students or between them and the teacher (de Mello, Shirley, 2013). Further, collaborative learning by using simulation during the lecture prior to a hands-on laboratory session considerably augments the experimentation skills of the students.

Data Analysis

Data analysis refers to the ability to collect, analyse, and interpret data, and to form and support conclusions (Feisel & Rosa, 2005). Data analysis is very important for the field of engineering in order to ensure devices and processes are working effectively. Therefore, learning of analysis and interpretation techniques in the laboratory is significant.

Studies suggest that virtual laboratories allow students to focus more on data analysis as compared to traditional laboratories (Williams, 2012). Primarily this is because the data is automatically collected by the computer freeing the student for greater manipulation and analysis (Parten, 2003). In physical laboratories the students spend a lot of time in data collection and data entry. Therefore, it can be concluded that in physical laboratories students have a chance to learn the data collection process from a very crude level which may be time consuming; and there is often a minimum use of technology in facilitating this process. However, in virtual laboratories, the experimentation is supported by computational tools to support the data collection and analysis on behalf of the scientists (Williams, 2012).

Design

Learning to design, build, or assemble a part, product, or system using appropriate tools to satisfy requirements is another important purpose served by laboratories (Feisel & Rosa, 2005). This domain covers all engineering disciplines because they are frequently involved in designing new products or processes to generate functional utility.

Physical laboratories are highly characterized by their emphasis on design skills where engineers learn to design, build and develop different products by manipulating matter and energy. Elawady & Tolba (2009) suggest in their literature review that half of their reviewed articles highlighted design skills as a major mission of physical laboratories. Contrary to this, Williams (2012) claims that the environment of virtual laboratories allow students to focus more on design as compared to physical laboratories. These contrasting assumptions are suggested to be a result of a vast domain of the “design” objective which encompasses a wide span of designing, building and assembling activities, representing different levels of learning (Most & Deisenroth, 2003). Further, the initial phase of the designing electronic circuits for physical laboratories often includes a simulation stage. Thus, improvement in design skills can be a learning outcome of virtual laboratories but they are ineffective in providing a circuit building or assembling experience to the students.

Learning from failure

Another significant objective is being able to identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design (Feisel & Rosa, 2005). In engineering, the major causes of failure may come from a flaw in design, material failure, environmental factors or a combination of all of these. In case of failure, it is important to assess all of the possible factors involved therein; therefore, this process may be lengthy, time consuming, costly and strenuous.

Novice learners tend to make mistakes when working with new equipment or technologies. Physical laboratory sessions are usually time bound based on relatively short sessions which may leave the student stuck in the problem until the next session which increases their anxiety and frustration. Further, the cost of failure in physical laboratories can be high and unaffordable as it might be hazardous to people and equipment (Williams, 2012). On the other hand, virtual laboratories provide space for achieving the goal of learning from failure by allowing the students to have repeated tries with no time limitation. Students have the freedom to redesign; use a variety of material options available and also measure the impact of different environmental factors available within the software. It also promotes self-learning resulting in improved error handling skills (Lampi, 2013). Further, being repeatedly exposed to different failure modes updates the student about various potential causes of failure in an experiment.

While virtual laboratories assist with exploring design flaw failures, explicit attention is needed to deal with equipment failure to fulfil this learning objective. Learning about equipment failure needs to be considered explicitly in virtual laboratory design, it may not be sufficient to have virtual equipment that always works.

Creativity

Demonstrating appropriate levels of independent thought, creativity, and capability in real-world problem solving is also among the goals laboratories should achieve. The creative aspects of engineering are reflected by increased freedom for design and experimenting (Most & Deisenroth, 2003).

If creativity and innovation are to be fostered, the students must be involved in developing the design of the experiment and should be given autonomy to develop an understanding of the uncertainities and inaccuracies of the outcomes of their experimental designs. This depends upon independent and critical thinking that requires freedom of space and time (Feisel & Rosa, 2005).

Physical laboratory sessions are usually time bound providing minimum room for creativity and in-depth thinking (Most & Deisenroth, 2003). Further, a limited selection of equipment in the physical laboratories implies short sessions with large groups resulting in crowd and fuss. Contrary to this, virtual laboratories provide anytime anywhere access to the students without time and cost limitations allowing enough time for creativity. They also provide students with the autonomy to deal with the problem using innovative methods and get things done their way. Thus, virtual laboratories are claimed to encourage creativity of students.

Psychomotor Skills

Psychomotor skills refer to demonstration of competence in selection, modification, and operation of appropriate engineering tools and resources (Feisel & Rosa, 2005). Studies tend to measure the psychomotor skills of engineering students considering the time taken to complete the experiment.

Romano, Sharda & Lucca (2005) claimed that there is no significant difference in the psychomotor skills of students working in virtual laboratories as compared to physical laboratories. Contrary to this, Lampi (2013) argue that a substantial disadvantage of virtual laboratories is that they fail to teach various psychomotor skills to the students as they cannot provide the real world experience of operating the equipment. For instance, a mechanical engineer would be unable to encounter the sense of acceleration, angular acceleration or altitude of the real experience when learning aerodynamics. Therefore, the students working on virtual laboratories would not be able to recognize and react to the circumstances involving such psychomotor factors.

The results for this objective show mixed findings depending upon the difference in definition or the method used to measure the psychomotor skills. However, development of psychomotor skills is a significant challenge for virtual laboratories.

Safety

Engineering students also need to be aware of the health, safety, and environmental issues and also learn to deal with them responsibly. Laboratory safety is extremely important, particularly in undergraduate laboratories where students first develop practices and habits that they may carry with them throughout their career.

Real laboratories like fluid power laboratories involve a great deal of safety and cleanliness where students may learn to follow safety precautions (Urdaneta & Garrick, 2012). Virtual experiments are seldom subject to any health, safety or environmental issues providing few opportunities to learn how to deal with them (Feisel & Rosa, 2005). This is because the experiments are either being performed by simulation, or in remote laboratories at a distance. Consequently, the element of danger and hazard is eliminated in virtual laboratories and students may never learn to care about safety issues that may arise in real laboratories.

For the first time, Bell & Fogler (1999) suggested that a series of virtual laboratory accidents must be designed to increase safety awareness in the students working on the virtual laboratories which would allow the development of safety awareness. The simulations should include safety instructions such as reminders to put on eye-piece, gloves, and lab coats before commencing the experiment and other similar safety warnings when dealing with hazardous materials during the experiment.

Communication

Communication refers to effectively reporting the results and laboratory experience to the specific audience which may be in the form of oral presentation, group discussion or written report. Further, informal communication between the tutor, mentors and students also help in the learning process; however, of all these the most critical for engineers is technical report writing (Riemer, 2007).

The isolated learning in virtual laboratories is found to discourage informal communication between the tutor and the student (Chan & Fok, 2009); and the distant learners in particular need to communicate with the teacher via email or video conferencing. Nevertheless, both the laboratories show no effect on the written communication skills because in both cases students need to generate professionally written lab reports (Feisel & Rosa, 2005). Most studies reveal that engineering students often fail to meet the quality standards of writtencommunication despite having completed various written tasks including laboratory reports and project reports. They often require assistance in organizing and structuring their arguments (Riemer, 2007).

Virtual and physical laboratories are equally effective for developing report writing skills of engineering students.

Teamwork

Engineers must learn to work effectively in teams. Working effectively in teams refers to individual and joint accountability; assigning roles, responsibilities, and tasks; monitoring progress; meeting deadlines; and integrating individual contributions into a final group report

(Feisel & Rosa, 2005). Team-based projects enable students to learn various peripheral skills in addition to teamwork. These include planning, estimating, tracking progress, taking corrective actions, managing change, controlling and managing risks, maintaining ethical and professional conduct, communicating complex ideas clearly and concisely, using design automation tools, leveraging web-based tools for team collaboration, and most importantly participating effectively as team members (Lingard & Barkataki, 2011).

Studies show that virtual laboratories tend to promote fewer social skills such as team work and communication as compared to physical laboratories. The remote features of virtual laboratories such as the disconnection of students in time and space are responsible for reduction in interaction. However, the design of the curriculum can be altered to promote team-based working in project teams with clearly defined roles and also by attributing success or failure to overall team's progress (Chan & Fok, 2009). As the business world becomes increasingly connected via Internet technologies, virtual teams continue to increase in number and importance. In addition, the emergence and growth of distance education also supports the increasing use of virtual teams (Nory C., Matt, 2015). This would promote teamwork, professional negotiation and brainstorming skills in the students. Further, teamwork can be promoted in activities within the curriculum other than laboratory sessions.

Ethics

Ethics for engineers refers to (1) increased ethical sensitivity, (2) increased knowledge of relevant standards or conduct, (3) improved ethical judgment, and (4) improved ethical will power (Williams, 2012). It is also claimed that ethics in engineers are the characteristics of morality in making the right choices when a problem situation is encountered. Engineering ethics in particular, refers to the rules and regulations that guide the engineers in leading their role during their professional life (Clancy, Quinn & Miller, 2005).

Engineering graduates need to meet ethical standards in reporting and using the university's property. Whether working in virtual laboratories or physical laboratories, they are supposed to work ethically (Feisel & Rosa, 2005).

An empirical study conducted by Clancy, Quinn & Miller (2005) based on two focus groups incorporated case studies in the engineering course with the primary objective of increasing students' awareness of ethical issues in the workplace. All the students agreed that their awareness about the ethical concerns in laboratory increased by such a laboratory session. Therefore, it is suggested that both physical and virtual laboratory sessions should include case studies related to ethical issues in order to enhance the ethical awareness among the students.

Sensory Awareness

Sensory awareness refers to using the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems (Feisel & Rosa, 2005). Human senses enable the engineers to feel, hear, and see things happening around them, sense the relevant issues and react to them accordingly. During the laboratorysessions, students develop their sensory awareness about the physical changes in the materials, energy and information and establish sensory patterns in their brain regarding their cause and effect.

In physical laboratories students experience all the physical changes and evaluate the impacts in real terms. All their senses are involved during the experimentation and a good deal of sensory awareness is established in their brain which enhances their learning experience and improves their overall expertise (Lampi, 2013). Hands-on laboratories give students sensory and situational awareness, which a virtual environment cannot reproduce. They can only see the experiment on the screen and in some cases hear the real audio; but they rarely develop the sense of touching and relating to real time situations that exists in a physical experiment; therefore, they might not react to the problem situation as well as a student who has physically experienced the situation (Feisel & Rosa, 2005). Live audio and video from the remote laboratories can make the experience more convincing and believable (Lampi, 2013). Nevertheless, the virtual laboratories cannot replace the physical laboratories in developing a similar sensory awareness in the students (Elawady & Tolba, 2009).

Discussion

The detailed analysis based on the thirteen learning objectives of engineering laboratories revealed an interesting picture of the utility and drawbacks of virtual laboratories. The first five objectives dealing with cognition – Instrumentation, Models, Experimental Design, Data Analysis, and Design – Suggests that virtual laboratories for the student that it's arguable, in the context of deeper learning, there can be no substitute (Bright G, D K Liu, D B Lowe C, Lindsay D & S Murray 2007). The virtual laboratories give a much better understanding and combination of the instruments; proper evaluation of the models, increased freedom for experimenting and designing; and help in data analysis as well (Elawady & Tolba, 2009).

Secondly, the two objectives involving the psychomotor domain – Psychomotor and Sensory Awareness – were found to be better in physical laboratories. Hands-on laboratories give students sensory and situational awareness, which a virtual environment cannot reproduce (Lampi, 2013).

Thirdly, behaviour and attitude related attributes – learning from failure, creativity, safety, communication, teamwork, and ethics – showed mixed results. Virtual laboratories are better in terms of allowing learning from repeated failures, and freedom for creativity (Feisel & Rosa, 2005). Both types of laboratories deal equally well with communication and ethics (Chan & Fok, 2009). Special effort and support is required in the areas of safety and teamwork if virtual laboratories are to deal with these areas adequately.

Conclusion and Recommendations

With the recent advances in technology-enabled education, the nature of laboratories has transformed. Virtual laboratories are increasingly being used as an alternate or supplement to the physical laboratories (Budhu, 2002). But simple virtual laboratories alone may not provide adequate learning opportunities in critical areas such as learning from failure, links between theory and models, safety, ethics and sensory awareness. Therefore, in order to fully achieve the goals of engineering laboratories, curriculum designers need to combine the positive aspects of physical and virtual laboratories (Feisel & Rosa, 2005). Studies suggest that virtual experimenting adds to the learning experiences offered by physical experiments (Lang, 2012; Parten, 2003).

Our experience is that many existing physical laboratory activities are designed without specific attention to a clear set of desired learning outcomes. Furthermore, there is limited correlation between the assessment of laboratory components of courses and these learning objectives. So it is not surprising that full analysis of desired learning objectives is also missing in many virtual laboratory designs.

In terms of explicit learning about the nexus between theory and practice, well-designed virtual laboratories can provide similar learning experiences. They can encourage experimentation and creativity.

In the areas of psychomotor skills, familiarity with physical equipment, building of physical prototypes, safe working, and learning from unanticipated failures, it is difficult for virtual laboratories to fully replicate the experience of physical laboratories.

The areas of creativity, communication, teamwork and ethics are learning objectives which are relevant across the whole curriculum, and are not specific to virtual laboratories. These objectives do not depend on the availability of physical laboratories.

According to de Jong, Linn, & Zacharia (2013) virtual laboratories help students by ‘allowing students to explore unobservable phenomena; link observable and unobservable phenomena; point out salient information; enable learners to conduct multiple experiments in a short amount of time; and provide online, adaptive guidance’ (p. 308). Therefore, the focus of modern universities should be on designing hybrid laboratories and also altering the curriculum accordingly to ensure that all the learning objectives of engineering laboratories are achieved in full.

References

Bell, J. T., & Fogler, H. S., 1999. *Virtual laboratory accidents designed to increase safety awareness*. Proceedings of American Society for Engineering Education Annual Conference, Charlotte, NC, American Society for Engineering Education.

Budhu, M., 2002. *Virtual Laboratories For Engineering Education*. Manchester, U.K., ineer.org.

Chan, C. & Fok, W., 2009. *Evaluating learning experiences in virtual laboratory training through student perceptions: a case study in Electrical and Electronic Engineering at the University of Hong Kong*. Engineering Education, 4(2), pp. 70-75.

Clancy, E., Quinn, P. & Miller, J., 2005. *Assessment of a Case Study Laboratory to Increase Awareness of Ethical Issues in Engineering*. IEEE Trans. Educ., 48(2), pp.313-317.

de Jong, T., Linn, M. & Zacharia, Z., 2013. *Physical and Virtual Laboratories in Science and Engineering Education*. Science, 340(6130), pp. 305-308.

Elawady, Y., & Tolba, A. S., 2009. *Educational objectives of different laboratory types: A comparative study*. International Journal of Computer Science and Information Security, 6(2), pp. 89-96.

Feisel, L. & Rosa, A., 2005. *The Role of the Laboratory in Undergraduate Engineering Education. Journal of Engineering Education*, 94(1), pp. 121-130.

Hatherly, P., Jordan, S. and Cayless, A., 2009. *Interactive screen experiments—innovative virtual laboratories for distance learners*. Eur. J. Phys., 30(4), pp.751-762.

Lampi, E., 2013. *The Effectiveness of Using Virtual Laboratories to Teach Computer Networking Skills in Zambia.* Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University.

Lang, J., 2012. *Comparative Study of Hands-on and Remote Physics Labs for First Year University Level Physics Students*. Transformative Dialogues: Teaching & Learning Journal, 6(1), pp. 1-25.

"Learning Science and Technology; Studies from National Taiwan Normal University Describe New Findings in Learning Science and Technology (Learning differences and eye fixation patterns in virtual and physical science laboratories)", 2015, Education Business Weekly, pp. 103.

Lingard, R. and Barkataki, S., 2011. *Teaching teamwork in engineering and computer science*. In Frontiers in Education Conference (FIE), 2011, pp.F1C-1.

Most, K. R. & Deisenroth, M. P., 2003. *ABET and Engineering Laboratory Learning Objectives: A Study at Virginia Tech. Blacksburg, Virginia, American Society for Engineering Education*.

Parten, M., 2003. *Using virtual instruments in a measurements laboratory*. Texas, Texas Tech University .

Riemer, M., 2007. *Communication skills for the 21st century engineer.* Global J. of Engng. Educ, 11(1), pp.89-
100.

Romano, N., Sharda, R. & Lucca, J., 2005. *Computer-Supported Collaborative Learning Requiring Immersive Presence* (CSCLIP): An Introduction. Inf Syst Front, 7(1), pp.5-12.

Urdaneta, L. V. & Garrick, R., 2012. *Implementing A Virtual Laboratory for A Di-Rected and Synchronous Student Learning Experience; Combining Virtual and Real Experimentation: An Effort to Enhance Students'conceptual Understanding of Fluid Power*, American Society for Engineers.

Williams, M. S., 2012. *Trends in engineering education: using ABET's program outcomes as a framework for change* , Columbia, MO: School of Information Science and Learning Technology.

LIU, D., LOWE, D, LINDSAY E. & MURRAY, S. (2007) *Remote laboratories in Engineering Education: Trends in Students' Perceptions. IN SØNDERGAARD*, H. & HADGRAFT, R. (Eds.) AaeE 2007

BRIGHT,C , LIU, D., LOWE, D, LINDSAY E. & MURRAY, S. (2007) *Remotely Accessible Laboratories – Enhancing Learning Outcomes*. AaeE 200

BRIGHT,C, LIU, D., LOWE, D, LINDSAY E. & MURRAY, S. (2008) *Establishment reality vs maintenance reality: how real is realenough?*

Rainer Mausfeld (2013), *The attribute of realness and the internal organization of perceptual reality* Dante Alighieri Alves de Mello, Shirley Takeco Gobara , (2013) *Analysis of Interactions in a Virtual*

Learning Environment Based in Vygotsky's Theory by da de mello
C. Matt Graham, N*orry B Jons (Mar 2015) Virtual Teams in Business and Distance Education pp : 3,4*

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