Vidya (2019) Vol : 14(2)

Review Article

ISSN: 2321-1520

Virtual Laboratories in STEM Courses: A Critical Review

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Received Date: 14-8-2019

Published Date:15-9-2019

Abstract

Computer Science courses demand extensive laboratory work as well as strong subject knowledge. Information technology resources have given wings to innovations and advancements by providing an artificial educational environment, which can be used along with the traditional environment. Such virtual environments provide many advantages like students are not required to install costly software or need not have specific set up for the desired course, just an internet connection, and a browser can serve the purpose. There are very few systems equipped with virtual laboratory experiments, along with tutorials related to the subject. The computer science courses particularly lack this type of learning management systems (LMS). Most of the Virtual laboratories reviewed are either just simulator-based or are some remote environments accessed through the cloud. Majority of the Virtual laboratories exist in Basic Sciences and other Engineering domains, whereas Computer science courses have very limited virtual laboratories.

Introduction

E-learning is a concept which evolved as online learning and utilized different forms of electronic

technologies, unlike a traditional classroom concept. Initially, e-learning resources were used as assisted teaching in classrooms for displaying videos, animations, etc. for better understanding of the concept. E-learning platforms are becoming critical platforms not only for educational institutions but also for corporates and individuals for lifelong learning

Web technologies are reshaping the education systems, and the innovations in technology have the ability to take education systems to new dimensions. The Learning component, Teaching-Learning methods, Flipped learning, Blended learning are all the significant researched areas in the education systems.Each Year (Educause) surveys the Higher education community to determine the areas of improvement in the Teaching and Learning Process.

The picture in Figure 1 represents key issues of Teaching and learning for the year 2019.

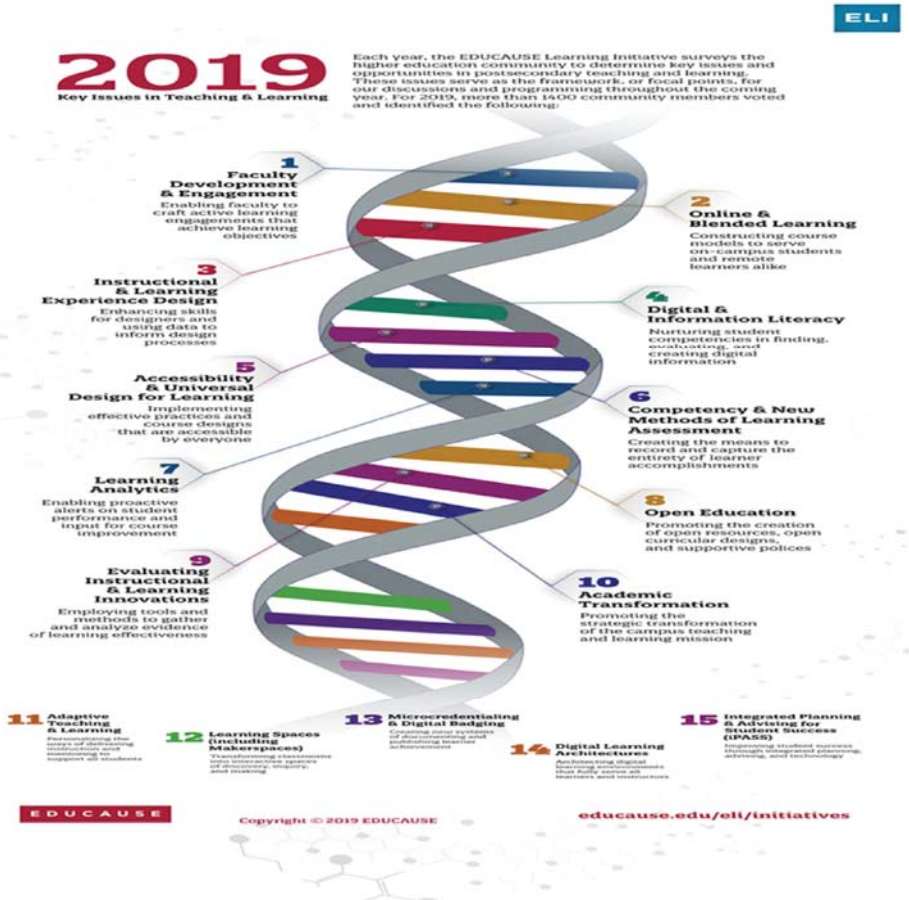

Figure 1: Teaching-learning issues (Educause, Issues in Teaching and Learning)

These types of surveys help the Academicians to address the teaching-learning process and bring the technological advancements with a clear focus on innovative pedagogical approaches.

The evidence of flipped learning's effectiveness is nonetheless plentiful in the area of educational research since 2014. 2017 alone had 131 peer-reviewed articles on flipped learning. (Robert Talbert). However, the term flipped learning is rapidly getting attention from the research communities in varied forms and approaches. Some researchers believe that just using technological aids gives the teaching a label of flipped learning, whereas there are researchers who have insisted that classroom-based learning is inverted to deepen the understanding among students which helps to make the process of understanding more effective.

Modern Re-usability frameworks assume that a learning object is a moveable entity (Brusilovsky & Nijhawan, 2002), Data which is stored in a repository and can be reused by copying on the destination client. But in advanced re-usable objects, activities are delivered by a Web Server(Brusilovsky & Nijhawan, 2002) which need to reside permanently on a web server and can be accessed by multiple clients. Here, researchers suggest that the learning activities should be adaptive based on the environment and student needs. It promotes courseware reuse and adaptive educational systems. They propose a knowledge tree where learning goal or objective is adaptive with the learning need of the student.

(Olin, Bourne, Mayadas, & Consortium, 2005) believe that Learning effectiveness, student satisfaction, Faculty satisfaction, access, and cost-effectiveness are the five metrics that drive investigations into online education.

Computer Science is one discipline that uses the growing and demanding e-Learning environment to deliver the computation and technology and knowledge to the learners. Computer science needs practical sessions as the main part of its education process(Fechner, Keller, & Schiffmann, 2005a).

The engineering bodies for accreditation (ABET) also strongly recommend for lab sessions/ practical sessions in their evaluation criteria.

Laboratory work is an integral part of computer science courses. The rise of technological advancements has led to innovations and improvement in the online educational system, including

online learning courses. The innovative approaches help the courses to be designed as per the changing requirements of the next generation learning. To achieve effective learning, laboratory work should be integrated with e-Learning environments. For courses like Computer Science laboratory work is an integral part of learning, thus providing a virtual laboratory environment for computer science courses can prove beneficial.

As our focus is on computer science domain, the limited duration for Lab sessions and fixed lab time slots in most of the colleges make the lab work limited or restricted to a particular time slot. The need of today's era is to let the student's practice/implement lab work in their pace and time. To provide such a facility, a separate infrastructure in the form of remote laboratories is required.

Virtual laboratories offer flexibility, allowing students to visit laboratories at odd times and enabling them to revise concepts as and when needed. Additionally, Virtual laboratories are beneficial in situations where the students are deprived of the laboratory infrastructure or have insufficient access to the laboratory resources.

Table 1: Traditional Laboratories Vs Virtual Laboratories

Traditional Laboratory	**Virtual Laboratory**
Fixed Time and Place	Any time and Place, based on the user's requirement
Expensive	Less Expensive compared to Traditional Laboratories
Learning and Assessment are done as per traditional methods of teaching	Complete Learning Management System(LMS) at one place
All students addressed in one group at one time	Personalized Learning
Less student engagement	Higher student engagement
Teacher/Learner-centric Pedagogy	Learning Centric Pedagogy

The Virtual Laboratories highly emphasize on **Student Engagement**. The digital platform brings with them the limitation of being diverted easily from the focus area. Hence, if the developers want a student to spend more time in a virtual laboratory, and practice and learn more, then the system developed

should be more engaging. The system needs to focus on learning-centric pedagogy to achieve the same. The experiments should be designed in such a way that students enjoy learning, which could be achieved by properly defining the Learning Objectives. The Learning objectives, in turn, should be aligned with the cognitive levels which help in catering the needs of all types of students and engaging all types of students. The appropriate cognitive level selection helps in defining the task correctly, and hence, the assessment gets adequately represented.

The joint ACM-IEEE Curriculum Task Force (1989) recommends thatcomputer science courses should be supported by extensive laboratory work.

In computer science courses, laboratories are an integral part of the learning experience. The instructors must consider all the objectives of the subject while designing tasks for laboratory-related work.The Learning objectives provide a clear idea about the outcome expected from the course getting designed.As, In today's world, students are turning towards e-Learning environment, it becomes essential that e-Learning environments are able to integrate virtual laboratories to provide complete learning.

RELATED WORK

There are many e-Learning repositories and courses available on e-Learning contents. However, the e-Learning contents mainly focus on delivering content to a mass audience and allow sharing of pools. These type of learning environments do not provide student interaction, and their primary focus is good quality e-content/tutorials. However, laboratory work is equally important, along with good quality course content. With the increasing technological advancements, even the laboratory work is required on the e-Learning platform, which results in the laboratories being available remotely. Hence, there is a need for Virtual Laboratories. However, good quality Virtual Laboratories are rare. The computer science virtual laboratories are even lesser. Virtual Laboratories in education are referred to as the simulation environment that adds an environment and human touch to the virtual interfaces (Virtual Laboratory, 2019). The primary purpose of a Virtual Laboratory is to provide remote access to laboratories in the area of science and engineering. The virtual environment gives an advantage of sharing costly equipment's which otherwise might be limited to a few users due to constraints on time and geographical distances. Such virtual

environments provide the benefit of addressing a large number of students at once, and the subject expert develops the content at one location, which can be accessed by students in different geographical areas. The virtual laboratory research is still in its infancy stage, and there is an acute dearth of good quality virtual laboratories.

A whole heap of research already exists on e-Learning systems and different online learning materials or learning courses. However, all those e-Learning contents involve delivering the content only; very few of them include live student interaction or student engagement. In the past,researchers have suggested that the learning activities should be adaptive based on the environmentand student needs. It promotes courseware reuse and adaptive educational system

Computer Science courses are not entirely instruction-based, and most of the subjects demand extensive practical work along with the conceptual clarity of the said subject. The traditional laboratories are the solutions for the implementation of the concepts learned.However, with the growing Information technology needs and innovative learning environments, the demand is to have laboratory access at their own pace, time, and place. Plenty of research isconductedto provide the students with the traditional laboratory environment on a virtual platform while also making the entire experience more interactive.

(Bourne, Harris, & Mayadas, 2013)suggests that the e-learning tools should be comparable with the traditional classrooms. They believe that learning effectiveness, student satisfaction, faculty satisfaction, access, and cost-effectiveness are the five metrics that drive investigations into online education.

Many researchers have argued that the students have started losing interest in traditional eLearning curriculum. The area of Learning requires significant innovations, wherein the student's interest can be maintained and adhere to the learning capacity of the students concerning different learning levels of the students. However,STEM (Science, Technology, Engineering, and Maths) courses still demand more efforts in learning skills. The engineering or computer science course is not complete without the laboratory work.Hence, there is a demand for the virtual/remote laboratory which can satisfy student's need for practical implementation in the digital content. However, to make laboratory learning effective and maintain student's interest, the pedagogical perspective has

a vital role to play. The pedagogical effectiveness helps design the course with all the learning objectives in mind, which results in a learning-centric virtual laboratory getting developed.

(Fechner, Keller, & Schiffmann, 2005b) discuss that Computer Science is a discipline that uses the growing and demanding e-Learning environment to deliver the computation, technology, and knowledge to the learners. Computer science needs practical sessions as the central part of its educational process.

In other engineering disciplines, researchers have proposed the following virtual laboratories.

(Smith, 2004)introduced an online simulator for Microelectronic devices. They designed and implemented an MIT device simulation WebLab (WeblabSim). It was an online simulator wherein the students could explore the behavior of microelectronic devices. WeblabSim makes device simulator readily available anywhere, anytime.

In August 2005, (Kantzavelou, 2005)proposed a virtual lab model for introductory computer science courses. The model consists of seven modules, and each one corresponds to a specific topic of the course. Every module provides several different services to a particular topic of the course. Every module offers various services to assimilate theory and practical exercises. The proposed model was partially implemented and gave a better understanding of theoretical concepts

(Kuleshov, 2008) Rightly points out that the interactive simulations allow students to explore a topic by comparing and contrasting different scenarios. Users may get more in-depth exposure to the subject matter either by modifying parts of existing simulator or by building a new simulation from scratch.

In 2015, (Al-Khanjari & Al-Roshdi, 2015)proposed the usage of Service Oriented Architecture (SOAs) to overcome the limitation of Learning Management Systems towards the practical implementations in computer science education. The developer uses SOA to develop the required resources as services and then integrates them in the LMS.

In February 2016, (Mendes, Li, Bailey, Delong, & Del Alamo, 2016)proposed a web services approach to support interactive LabVIEW based Remote experiments under MIT's iLabShared Architecture(ISA). Experiment lab server Architecture (ELSA) was developed as an extension to

ISA, fulfills the requirements of an ISA process agent and uses web services to connect the client with the lab Server.

In November 2016, (Velasquez, Ramos, & Amaya, 2016) reviewed different technologies which could be used for the development of different types of virtual/remote laboratories in the education system. They conclude that the Remote Laboratories (LRS) lack interactivity and there are many technologies available which could be integrated to develop aninteractive LR. They also explored various disadvantages of techniques which require compulsory installation of add-ons as a prerequisite. Such considerations should be eliminated to create an interactive and open platform LR/VR.

Additionally, there are other educational areas which are also explored concerning Virtual laboratories like Languages, Gamings, etc. One of the language lab named as "The Virtual Language Lab," which helps the students to learn a foreign language in a virtual environment. (Mads Bo-Kristensen, 2008)insist that even before the virtual lab was implemented pedagogically and practically, new significant options of Mobile language lab had emerged. And even before the latest lab displayed its pedagogical potential, yet another lab scenario was ready in the form of pervasive computing and learning.

Understanding the need of user interaction for effective learning, MHRD initiated Virtual Lab project. Virtual labs project is collection of many virtual laboratories consisting of different experiments in the field of Science and engineering. The project is anconsortium of many Participating institutes and IIT-Delhi is the coordinating institute. The Virtual laboratories are available in the areas like Electronics and Communication, Biotechnology and Biomedical , Computer Science, Civil engineering, Physical sciences , Electrical, Mechanical and chemical engineering. The new labs developments include many innovative areas and technologies. One of the major advantage of virtual laboratories is they are not just simulator based , but they are the entire Learning Management System at one place.

Virtual lab project is dedicated to address the basic problem of lack of good lab facilities in many engineering colleges. (Bose, 2013)

Virtual labs is more than just providing laboratory access to students , It enhances the students

thinking capacity and motivates him to learn more. As(Bose, 2013) rightly mentions that good teachers are always a scarce resource. Hence, such Virtual lab project is an Open Educational Resource (OER) that addresses the issue of lack of good lab facilities, as well as trained teachers by making remote experimentation possible.

The Virtual lab project is intended to benefit varied communities like Students and Faculty members , High-school students whose inquisitiveness would be triggered, Researchers, who can collaborate inter-institute or inter-discipline and Different engineering colleges. (Bose, 2013)

Conclusion

Authors could review *that* various remote or virtual laboratories are mostly based in engineering disciplines. Most of the models proposed were simulator-based and provided access to the program on a remote computer or a server.Authors believe that a virtual laboratory proves more efficient if it caters to all the needs of a complete Learning Management System and provides step-by-step guidance in the process of learning.

The virtual laboratories available are just simulator based and not able to provide guided learning. There is need to create complete LMS, considering all the Teaching Learning aspects such as pedagogy of teaching and learning, student engagement and cognitive levels. All the cognitive levels from Recall to Create should be considered to facilitate higher order of learning to students. The virtual laboratories should be such that students should seek to spend more time and should feel that they can learn more by using the virtual laboratory. The online labs under the Virtual labs project not only arouse curiosity in students but also permit them to learn at their own pace.

Many virtual laboratories have been developed and are being developed, but there is lot of scope of improvement in virtual lab design and development. Also sometimes E-Learning platforms are not as effective as traditional classroom based learning, because of one major factor.In classroom based approach a teacher can teach with different methods and different pace to each student according to their grasping capabilities. Hence, Development of smart virtual lab which can give personalized learning experience to each student as per their pace of learning and needs is an open issue for researchers to explore.

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