Advanced Techniques used to enhance Practical Approaches in Pharmaceutical Chemistry

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Abstract

Practical work plays a vital role in effective teaching with better learning outcomes hence gaining practical skills in the laboratory in a pharmacy course is of utmost importance. Design; development, analysis and synthesis are the main part of pharma chemistry. The process of imparting quality education and laboratory skills comes up with challenges such as improper disposal of laboratory waste either of chemical, biological or radioactive nature is tedious and needs to be regulated by the regulatory agencies and this is expensive. Not having to meet the regulations, such practices pose severe threat to aquatic environment and bring environmental hazard. Other challenge being mutations of microorganisms which leads to the outbreak of pandemics which results in lockdown of educational institutions which in turn affects the practical skills of students. Laboratory is a place where students aligns his scientific knowledge and apply in real practice right from drug discovery to development of new molecule. In order to overcome all the above challenges, technological advancements can be made use of one such is "Virtual Labs" these are computer operated, designed based on the cognitive approaches without physical contact conducted by simulations and are student centric. Students or researches can learn from QSAR studies, molecular modelling, and various spectroscopic studies to general chemistry which are conducted by a single virtual lab.

Key Words: *Advanced technology, virtual chemistry labs, Human-computerinterface, pandemics, laboratory practical skills.*

1. Introduction

Laboratory exercises in medical and para medical courses are an essential component of the technical education. In such courses, as experimental work in the laboratory is one of the most effective methods of gaining knowledge and acquiring a skill; and laboratory is a place where students can learn and align scientific knowledge and apply in real practice in future. Technology can be made use in the laboratory in order to facilitate more student centric and enquiry-based learning. Technology has touched all the aspects of life so as education, strong technical support, updated personnel; shifts in policy making are the pre-requisites of times in order to combat the global challenges which have led lockdown of the entire education system [1].

Technology has brought remarkable potential for learners and teachers to maximize in their effort. Research findings have proven that effective implementation of ICT (Information and expected level Communication Technology) can play a potential role in achieving the goals of teaching and learning [2], in spite of prevalence of advanced technology the usage in education sector, research, and communication is less than the availability[3], as it is based on cognitive approach which enhances the learning outcomes. Various technological tools have been used for engagement and assessment which includes Microsoft and Google Forms, Moodle, Web 2.0, Blackboard Collaborate, [4-7]which allows different modes of interaction with the students; however they have posed some questions, which has been extensively studied by the Towns Research group(Purdue University department of chemistry and Bretz Research group Miami university). These studies have revealed that there is inconsistency between students' expectation, faculty goals and learning outcomes across meaningful learning, psychomotor skills, and cognitive growth [8-11].

In order to overcome the above issues, an alternative environment is desired, which is called virtual laboratory. It is nothing but an environment in which experiments are conducted or controlled partly or wholly through simulation, computer operation via internet performing teaching and experimental activities without physical contact[12].Technological advancements have created an alternative to physical laboratory through virtual laboratory. As they are computer-assisted, physical and chemical simulated, they fulfil the conditions of an experiment[13, 14]. As these labs are learner-centred and inquiry-based, they help to promote higher levels of thinking and retention helps students to correct their concepts with immediate feedback and enhances meaningful learning[15].These blended learning labs are the ones where a student is exposed to the remote lab which serves him as supplementary tool for preparedness to the laboratory, chemicals, glassware and other equipment, help a student re-plan an experiment before carry it out in actual class prior to the exercise[16, 17],they also offer more possibilities to simulate and visualise quite a number of complexes understanding of scientific concepts[18, 19]. Moreover,students find these simulations of laboratory assignments motivating and create lot of fun and experience and research has claims that it enhances their cognitive tasks and enhances their learning processes[20].

In developing countries conducting experiments requiring sophisticated instruments is not achieved due to the lack of resources and economic conditions[21]. Such experiments can be accessed by two or even three-dimensional simulated environments. They bring economical ease on universities, maintenance with regards to laboratory equipment; personnel would be expensive in physical labs from the instrumentation, supplies point of view. They could also accommodate larger number of students in groups for the study which is difficult in physical lab, students can also learn from their mistakes repeatedly without having to cause damage to the platform which otherwise is not possible with traditional laboratories[22].Virtual labs provide the student effective learning though modelling the physical phenomenon by a set of equations and carrying out simulations giving better result of laboratory experiment and providing measured data though computer interface which can bring out the same effects of actual lab. They can also be made more realistic and effective by providing additional inputs to the students like audio/video streaming.

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2. Methodology

To identify the scholarly articles on existing virtual labs and their applications, we systematically reviewed Science Direct, Google scholar, Research Gate, Springer, Medline, and PubMed databases by using the following key search words: Chemistry lab education, Education under lockdown, pandemic and effect on education, Virtual labs in chemistry. Literature was gathered, scrutinized, collected relevant information; citations were checked visiting each virtual lab.

2.1 Exploring Non-Traditional Chemistry Labs

Table 1. Comprehensive list of chemistry virtual labs used in teaching & learning laboratory skills

S. No	Virtual Lab	Available concepts	Pharmaceutical Chemistry course specification	Affiliated to
1.	ACD/Spectrus processor *NMR work book suite *Structure Elucidator suite *Automated structure verification *Chem sketch suite *ACD/name version2019	An off-line desktop processing software assist spectral analysis, helps in interpretation of molecules, gives comprehensive reports for publication-ready data. Lab contains LC/MS, GC/MS, IR, and assigns LC/UV/MS Data electronically, predicts NMR chemical shifts, coupling constants for (^{1}H, ^{13}C, ^{15}N, ^{19}F, ^{31}P nuclei),. Chem sketch version 2019 analyses stereo bonds and generates stereo descriptors. With the name version 2019 one can generate ring and brand	Applicable Research Projects	ACD/Spectrus

		structures along with ring assembly.		
2.	Labster Labs	These labs have been developed with full interactive and advanced lab simulations based on mathematical algorithms that support open-ended investigations. They contain acid and bases and their reaction, building atomic structure, HPLC analysis, injection techniques, ionic and covalent bonds, Kjeldahl method of estimation of protein content in food. NMR application in analysing small protein samples, preparation of salts and solutions, stoichiometric calculations, neutralization of acid, lake contamination using titrimetric method.	Applicable Research projects	Labster.com
3.	Model ChemLab	These labs offer acid-base titrations, crystallization techniques, fractional crystallisation, gravimetric analysis, various analytical techniques, Redox titrations, cation, anion reactions, educators can create their own lab using its wizard tool and it is ideal for run-through demonstrations and pre-lab.	Applicable	McMaster University
4.	Virtual Labs Project	It contains UV-visible spectroscopic studies of conjugated molecules, calculations of vibrational frequency, SN2 reactions, geometry of molecules and its interpretation, PKa determination, analysing unknown concentrations using Beer-Lambert Law.	Applicable	MHRD Govt. of India
5.	Ph ET interactive simulations Lab	PhET offers general chemistry as well as quantum chemistry -based simulations. Concepts include atomic interactions, balancing chemical equations, /concepts of concentrations, building a molecule, isotopes, shapes of molecules, molarity calculations, including shapes and polarity of molecule.	Applicable	University of Colorado
6.	MERLOT Labs	This lab contains simulations signal processing in chemical analysis,	Applicable	California

	Chem Spider.com	resolution of peaks, integration of peak area measurements, acid base titrations, analysis of Gp-1 cations, HPLC simulator, spectrophotometric simulation is available, and its Chem Spider.com allows free chemical structural database.		State University
7.	Chem Collective	Titrations of acid-base, strong acid bases, weak acid and bases, buffers. Stoichiometric calculations include mole, molarity, density, limiting reagents, empirical formula and gravimetric analysis; it offers simulation of vibrational/rotational spectrum of a diatomic molecule, adjusting the molecular and experimental parameters students can observe the effects of the Infra-red spectrum.	Applicable	Carnegie Mellon University
8.	Chemistry Virtual Lab	It's an Arabic app where student can explore reactions of aldehydes and ketones,determine the physical and chemical properties and perform oxidation reductions reactions.	Applicable	Helwan University
9.	Yenka Labs	This is new generation educational modelling tool developed from Crocodile clips containing various aspects of Inorganic and physical chemistry model experiments and has a brief on electrochemistry, which helps in electrolysis, electroplating from carbon electrodes.	Applicable	Yenka Chemistry
10.	Virtual Labs at Amrita Viswa Vidyapeetham	Inorganic chemistry lab contains: acid base titration, gravimetric estimation of barium, nickel, soil analysis, water analysis. Physical chemistry lab contains calorimetry-water equivalent and heat of neutralization, cryoscopy, electromagnetic field measurements and spectrophotometry	Applicable Research Projects	National Mission on Education, MHRD, Govt. of India
11.	Visual Organic chemistry Lab	This lab offers basic techniques required for the synthesis, isolation, purification and identification of organic	Applicable	San Jose State University

		compounds. Synthesis of aspirin, identification of unknown mixtures, introduction to IR,NMR spectroscopy, esterification of unknown alcohol and GC of unknown alcohol mixtures		
12.	Organic Chemistry Laboratory website	This contains videos to advance organic chemistry laboratory skills like handling and disposing of chemical waste, melting point determination, single solvent and two solvent recrystallization techniques, TLC techniques, filtration techniques, science and techniques to using separating funnel, reflux(special reaction conditions), distillation at reduced pressures, and rotary evaporator.	Applicable	University of Alberta
13.	BYU Science Virtual Labs	It contains series of colorimetric estimation technique simulations. handling of gases (CH3, N2, CO2, NH3, He etc.,) interpretation of UV, IR spectroscopy, TLC techniques including titrations	Applicable including mostly in preparatory year	Brigham Young University
14.	Virtual Organic Chemistry laboratory: Interactive organic mechanisms *Chemistry QuickTime TV	This lab covers nucleophilic substitution reactions (SN1& SN2), elimination reactions (E1&E2), basics of reaction drawing including quiz questions. Reactions mechanisms, solid state chemistry, and an interactive tutorial on the analysis of IR and Raman spectra with theoretical methods. An interactive tutorial on Claisen reaction and synthesis of ketones from β-ketoesters. It also contains 12 minute steaming online TV channels explaining key topics to chemistry (atomic orbitals, structure of crystals, stereochemistry, Diels-Alder reaction). Scanning tunnelling study of Zn7 Metallothionein II- virtual flight around STM landscape followed by overlaying the protein onto the surface. A scanning tunnelling study of	Applicable Research projects	Oxford University

		immobilised Cytochrome P450 a virtual flight around a STM landscape followed by a flight inside the P450 protein itself.		
15	CSU ChemLab	This virtual environment based chemistry lab is designed as tool to prepare student in response to lack of confidence and a sense of anxiety taking up university practical sessions. It helps students develop skills in recording, reporting and interpreting observations, develop higher cognitive skill, and familiarity with the instruments, glass wares, chemicals etc.	Applicable (preparatory year)	Charles Sturt university
16.	UPM Virtual Labs: Green building Orange building Blue building	In these 3 buildings the visitor has tables with computers with access to various audio-visual materials and "quimitrivial-UPM, a preparation module (orange building) and Instrumentation (blue building), where students can perform the determination of the toxic elements (AS), arsenic, Cadmium (Cd), Chromium (Cr), Copper(Cu) and Lead (Pb) in the samples of contaminated soils and spectrometry with inductively coupled plasma (ICP-AES).	Applicable Research projects	University of Madrid
17.	Organic chemistry lab	Determination of functional groups in organic compounds in test samples, identifying the unknown compounds in mixtures. Synthesis and characterization of carbonyl compounds, IR spectroscopy.	Applicable	chem.libretexts.org
18.	Lila Labs (Nano Labs)	It contains six setups containing virtual pharmacy experiment, fluorescent dipoles, and electrochemistry.	Applicable	European commissions Lila-project.org
19.	Nmsu Virtual Lab	This lab prepares students in food lab science, Gram staining of bacteria and their sampling, corn mold, mycotoxins, virtual water activity virtual labs, and meter calibration	Research projects	New Mexico State University
20.	Gizmos STEM Cases	This virtual lab is designed based on the		

		latest national educational standards and compatible with the many devices and it contain a colorimetry lab.	Applicable Research projects	Gizmos
21.	Microsoft andGoogle Forms	These platforms offered the ability to integrate media content allowing instructors to scaffold experiments with targeted inquiries and encourage students to make decisions based on the selection chosen by students	Applicable Research projects	Survey platforms
22	3D Desktop Technology	They help students to develop realistic and accurate representations of laboratory environments, equipment which help students to familiarise with complete lab prior to real laboratory practices	Applicable	
23	Immersive VR Technology	Offers a high level of immersion in the laboratory environment. Offers 3D stereoscopic depth, IR spectroscopy head position/rotation, visual isolation from real world makes the user believe that he is in an actual lab with high level of realism which increases the motivation and engagement positively.	Applicable Research projects	North Carolina State University
25	Blackboard Collaborate	This platform allows to share notes and multimedia resource with students. Video conference/chat option where live presentations were delivered and grade centre was created in order to assess tests and surveys could be performed.	Applicable Graduation projects	University of Alcalá (Madrid, Spain
26	Thinglinkvirtual platform	Virtual instruments (X-ray fluorescence spectrometer and an ion chromatography system were created using software which allows users to upload images, variety of hotspots, text, audio files and links.	Research projects	The Kelee University, UK.
27.	Google Analytics O Labs	Contains 173 science experiments, provides animations, simulations and questions aimed at providing a deeper theoretical understanding. They provide a platform for supplementary learning.	Applicable	Amrita CREATE, Amrita School of Engineering

3.Discussion

3.1 Review of the existing virtual labs with their applications

It is the 21-st century education demand to redefine the role of educators facilitating their duties apart from traditional lecture halls and laboratories. Virtual laboratories are the most significant educational technologies of recent times. Different organizations have developed various labs based on open-source software depending upon their applications and usage, however student find them interesting as they are technology driven and instant feedback, flexible access and repeatability of the experiments at their ease.ACD/Spectrus[23] provides multi-technique vendor neutral and easy to use off-line desktop processing interpretation and reporting, its structure elucidator suite is a complete software package to help in the elucidation of unknown structures, the software predicts the 1D and 2DNMR spectra, chemical shifts, coupling constants for ^{1}H, ^{13}C, ^{15}N, ^{19}F, ^{31}P nuclei, it also verifies the structure by an auto mated structure verification.NMR workbook suite is a synchronized peak-picking among related NMR spectra, powerful structure assignment tool, and complete project management including data basing capabilities; it's a ultimate software tool for structure characterization by NMR. Chemsketch version of 2019 is a compiled 64-bit architectural software which helps in stereo bond and generates stereo descriptors. Its ACD/Name version 2019 software is compiled in a 64-bit architecture making it a great system resource; it helps in name to structure, stereoisomers, correction of names of different classes of compounds. Labster labs are developed with full interactive based on mathematical algorithms. Apart from HPLC analysis, it helps to know injection techniques, estimate protein content in food using kjeldahl method, and determines acid lake contamination using neutralization titration method[24]. McMaster University has designed simulation with combination of text-based practical's; educators can create their own lab using its wizard tool[7, 25].

In an MHRD (Ministry of Human Resource Development) initiated project from India, virtual labs are easily accessible to anyone who cannot afford to have traditional labs, apart from various spectrophotometric estimations; the lab explains SN2 reactions, and geometry of molecules[26]. PhET interactive simulations[27]lab has been developed by university of Colorado, can be accessible to anyone desires to, they are based on simulations with data acquisition programmes with pre-designed chemistry lab experiment of chemistry allows users to perform interactive chemistry lab, its lab wizard tool allows educators to create their own lab simulation apart from acid-base titrations, gravimetric analysis, Redox titrations and reaction kinetics. MERLOT is a California State University centre for distributed learning developed programme which provides tools and materials for learning in communities building shared knowledge. Virtual labs contain Acid base titration, interpretation of IR, NMR, MS spectra, 3D modes of molecular visualization, simulations signal processing in chemical analysis, resolution of peaks, integration of peak area measurements, analysis of Gp-1 cations and HPLC simulator along with spectrophotometer simulations. Its chem.Spider.com is a free chemical structural database[28].

National Science Foundation programme developed by Carnegie Mellon University is a Chem Collective lab which analyse food dyes, artificial dyes in drinks in qualitative and quantitative manner. It has stoichiometric calculations including mole, molarity, density, limiting reagents, empirical formula, and gravimetric analysis. It offers simulation of vibrational/rotational spectrum of a diatomic molecule, adjusting the molecular and experimental parameters. Students can also observe the effects of the Infra-red spectrum[29]**.**Helwan Universitycontains chemistry virtual lab in Arabic language, where students can explore various types of reactions containing aldehydes and ketones and oxidation reduction reactions[30]. Crocodile Clips have developed a virtual lab Yenka [31], which is a complete virtual chemistry laboratory containing inorganic and physical chemistry model experiments using wide range of chemicals and glassware. Its electrochemistry simulations can help investigate electrolysis, electroplating from carbon electrodes. Govt. of India, initiated Amritaviswa Vidyapeetham virtual lab contains physical chemistry lab containing calimetry-water equivalent determinations, heat of neutralization, cryoscopy, electromagnetic field measurements and spectrophotometry.

They can also perform gravimetric analysis, estimating nickle, barium. They also contain determination of PH of soil, water and soil analysis[32]. SPRING 2015 Chem 113A website was designed and developed at San Jose State university containing visual organic chemistry lab, it contains a course intends to instil basic techniques required for synthesis, isolation and purification; identification of organic compounds stressing more on the practical laboratory skills. Synthetic experiments include synthesis of aspirin, identification of unknown mixtures, Introduction to IR, NMR spectroscopy, distillation of alcohols using GC, significance of pKa values in experimental steps, assessing the purity of organic compounds using analytical techniques like melting point, TLC, IR, NMR, concepts of equivalent and non-equivalent hydrogen, effect of structure on chemical shift and coupling constants and gas chromatography. They also deduce organic structures using spectroscopic methods[33].

University of Alberta[34] contains organic chemistry laboratory website which contains basic and essential laboratory skills, provide an outline for the synthesis of organic compounds and spectroscopic techniques. This website contains videos to assist the student and enhance their learning outcomes which includes handling and disposal of chemical waste, single and two solvent recrystallization techniques, TLC techniques, handling and proper usage of separating funnel, reflux under special conditions, distillation techniques at reduced pressures and the use of rotary evaporator. Y Science Laboratories of Brigham Young University contains both virtual and realistic simulations as virtual ChemLab and Virtual ChemLab Organic[30]. Here the student is put into virtual environment where he is free to make his choices and decisions which cannot be confronted in actual laboratory which can result in consequences. Department of chemistry, Oxford University contains virtual lab which are interactive, aims at assisting in the understanding of simple nucleophilic and elimination reaction mechanisms along with quiz questions, they contain reaction mechanisms, solid state chemistry. They also contain an interactive tutorial on Claisen reaction and synthesis of ketones from β-ketoesters along with assigning spectra. Its chemistry Quick time TV contains 12-minute streaming online TV channels explaining various key topics to chemistry listed in Table-1. They also

have simulations around STM landscape of the enzyme Cytochrome P450, and Zn_7 Metallothionein II[35].

Charles Sturt university has developed CSU ChemLab[36]in order to prepare students to take up university laboratory task and to get familiarize with the lab itself, developed skill in recording, reporting and interpreting their observations and skills related to manipulative and instrument use and familiarity where students will later undertake their practical classes. However, this lab does not allow students to conduct experiments this is in response to evidence suggesting that many of the students experience lack of confidence and a sense of anxiety approaching practical sessions. Technical University of Madrid developed an innovation project UPM virtual labs[37] contains 3 building of chemical experimentation lab, green building where the visitor has tables with computer allowing the access to various audio-visual materials related to practical aspect of chemistry practices. Orange building being the instrumentation, and Blue building where students can detect the simultaneously toxic elements of arsenic, cadmium, chromium, copper and lead and subsequent analysis by atomic emission spectrometry with inductively coupled plasma (ICP-AES).

In its organic chemistry lab, student can prepare reagent to be used in practice and carry out identification of functional groups for the test samples. NEWTON project funded by the European Commission have large scale projects aiming to create virtual labs and bring them to main stream education, one such is the Lila Labsan initiative of eight universities and 3 enterprises for the mutual exchange of access to Nano virtual labs. They contain six setups with virtual pharmacy experiments and electrochemistry[38].New Mexico State University contains Nmsu virtual lab help students learn various laboratory techniques and practice methods by researchers specifically in food science lab processes like food lab science, bacterial and mould testing, controlling the water activity are some of the features of these labs[39].Gizmos STEM Cases, this virtual lab provides interactive simulations allowing students to learn chemistry concepts, it contains a colorimetry lab, based on the latest national educational standards and compatible with many devices which is the feature of this lab as lack of compatibility with the devices can greatly reduce the usefulness of a well-designed virtual lab[40].

Social Media platforms like Microsoft and Google Forms have also been designed offering students to integrate media content(videos, images, links to authors and questions which allow instructors to scaffold experiment with targeted inquired allowing students to make decisions by incorporation of branching points [6]. 3D Desktop technology labs were developed with more realistic and more accurate representations of laboratory environments (flasks, burettes, pipettes) than 2D Desktop labs which help student to familiarise with the laboratory prior to the real lab. Practices[41]. Immersive VR technology has emerged as a promising educational tool for chemical lab. With HMD VR devices, this technology offers a high level of immersion providing the feeling of realism. 3D stereoscopic depth, head position/rotation tracking and visual isolation from the real world make the student feel he is in actual lab[42].

Blackboard Collaborated was virtualized for the laboratory experiments which contains folders with different content could be uploaded, a grade centre was created where studentswere assessed, announcement section was created where surveys could be performed [4].Thinglink virtual platform allows the augmentation of images, videos to created interactive, visual learning experiences for users, it also allowed users to upload images and add a variety of "hotspot locations which provide a series of structured pathways through the resources [43]. Google Analytics Labs is a free platform of online laboratory access which has over 173 science experiments containing animations, simulations and questions aimed at providing deeper theoretical understanding. It does contain parameters like the number of users, the number of unique pages viewed per session; time spent on viewing content; bounce rate; and preference for content types[44].

3.2 Impact on learning chemistry education and the effectiveness ofvirtual laboratory to physical laboratory

Effectiveness of virtual labs achieving learning outcomes is critical to both students as well as to the educators and it's not only the variable which can be considered, they can be measured using variables like lab reports comparison from the experimental group students with that of the control group, developmental skills like data interpretation and analysis, research skills in-class test of the control group of students and evaluating student learning progress through academic achievement.

Virtual Laboratory is an emerging trend for technical courses, it allows students to conduct experiment in the labs repeatedly, practice in pace with their ease and time without causing damage to the platform, and can learn from their repeated mistakes which cannot be achieved in classical lab. It serves as a potential tool to boost student learning outcomes by allowing these labs introduce new strategies to help higher-level skills like information communication and self-management, independent learning, and cooperative learning. Literature has shown the learning chemistry laboratory through virtual labs has improved learning outcomes and confidence as compared to classical learning [45, 46] concepts learning is doubled in students who took these in comparison to their classical one [42, 47]. Infrastructure inadequacies, inadequate laboratory facilities, in-experienced personnel, over populated classrooms issues can be dealt smartly using virtual labs [48, 49]. Transforming the infrastructure into virtual lab is justified in tertiary educational institutions, they can bring effective learning outcomes starting from preparing student from lab exercise, prepare to perform research programmes after graduation [50].

Sharing of resources between different organisations and institutions can be effectively done and international projects can be handled with ease. Possibility of expanding virtual lab experiments in order to meet the requirement is a great relief and large community of students can benefit from such, there might be concerns regarding the effectiveness and realism of these labs, which has been taken care by [51], they have provided with the tools in order to overcome such challenges. These are some of the tangible and intangible benefits of a virtual lab with reference to a physical one where a student is able to gain, access to

knowledge, learn a technical skill though a few clicks on their phones, tablets and computers when technology has stepped to its breach, it will play a key role in educating university students in these disruptive crises. Classical method of passive, time-constricted, protocol driven learning is quite different to inquiry-based learning where student can expect from their learning by altering educators and learners' opinion on how practical skills are taught like time management, collaborative and peer assisted learning, online discussion forums, decision making, and design experiments based on the need of the hour and participate actively throughout their curriculum.

Table-2. Benefits of virtual laboratory over classical laboratory

Variables	Classical Lab	Virtual Lab
Practical skill development	✓	✓(variable)
Scientific approach to work	✓	✓
Economical in operation and maintenance		✓
Infra-structure inadequacies		✓
Availability round the clock		✓
Bound to geographical locations (International Projects)		✓
Effective knowledge retention(psychomotor)		✓
Size of the class		✓
Sharing of resources with different institutions		✓(variable)
Pre-lab preparation	✓(variable)	✓
Handling ofharmfulchemicals and their dangerous effect on health		✓
Risk of Plagiarism	✓ (high)	✓ (low)
Repeated and multiple access		✓
Access to Disability	✓	✓
Student-instructor contact	✓	✓ (variable)
Student distraction	✓(minimal)	✓(high)
Lack of confidence and a sense of anxiety		✓
Boosting IT Knowledge		✓
Continuous and effective education in cases of pandemics and other such emergencies		✓
Meaningful experimental results in relation to (access to chemicals, apparatus, lab.time and accent of the instructor)		✓
Interesting and student friendly as they are designed with the state-of-the-art technology of 21st century		✓

4. Conclusions

In a technological driven atmosphere, strong technical support, updated personnel, research-based techniques to enhance learning is the pre-requisite of today and it makes the student interested in such. Results have shown that these non-traditional labs are far more student centric and interesting than traditional labs, as retaining knowledge using such (audio-visual) has proved to be effective in comparison to classical mode of seeking laboratory knowledge. In traditional labs not all students can participate actively in the laboratory lessons and work due to external effects (like equipment, glassware, handling dangerous chemicals, accent of the instructor, limited class time, peer pressure, size of the class etc.) which can prevent the student from being active. On the other hand, virtual labs have user friendly software, are visually attractive and make learning more effective. This paper proposes the adoption of virtual labs as a standard learning tool in order to respond to the situations created due to pandemics or other emergencies, so that the effects of such situations should not hinder access to knowledge and students should be able to complete their courses in an effective way, as these students are the future generations and are the contributing members of society and an asset to the nation.

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