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What virtual laboratory usage tells us about laboratory skill education pre- and post-COVID-19: Focus on usage, behavior, intention and adoption

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Abstract

COVID-19 pandemic has brought uncertainty in educational response, skilling methods, and training practices among teachers and institutions. Even before the pandemic shutdowns, the incorporation of virtual laboratories within classroom education had brought transformations in teaching laboratory courses. Virtual laboratories were integrated as training platforms for complementing learning objectives in laboratory education especially during this pandemic imposed shutdown. In context of suspended face-to-face teaching, this study explores the role of virtual laboratories as Massive Open Online Courses (MOOCs) in ensuring the continuity of teaching–learning, providing alternative ways for skill training from home. As an innovative approach, the study presents push–pull mooring theory to analyze switching intention of users from offline conventional education to online education. The study explores the complements of physical experiments brought in with animations, simulations, and remote laboratory set-ups for providing skill trainings to learners. To test whether virtualization techniques have global impact in education sector, the study included a comparative analysis of student users during the academic year 2019 (before-COVID) who had a blended approach of learning and those of the year 2020 (post-COVID), with remote learning. Initial before-COVID behavioral analysis on university students (n = 1059) indicated the substantial popularity of virtual laboratories in education for skill training and instructor dependency. Usage adoption of virtual laboratories increased during the pandemic-imposed lockdowns and learners were being less instructor dependent. 24% of students accessed more 10 times a week without the instructor being present and overall, 90% contributed to a minimum of 5 usages a week. In terms of Kolb's learning styles, most of the virtual laboratory learners were assimilators. The results suggest virtual laboratories may have a prominent role in inquiry based and self-guided education with minimum instructor dependency, which may be crucial for complementing practice skills and planning online tools to add to this post-COVID-19 teaching and learning scenarios.

Keywords Virtual laboratories · COVID-19 · Technology acceptance · Kolb's learning · Assessment · Usage

1 Introduction

One of the unprecedented challenges in COVID-19 pandemic is the closure of education institutions in the affected countries for an indefinite period to prevent transmission of disease. In the midst of this pandemic, use of technologies within the context of distance education has gained substantial popularity for learning from home (Dhawan, 2020). All around the world, multidisciplinary approaches have been implemented in transforming education sector with integration of e-learning platforms as catalyst to overcome the present crisis in schools and university education (Soni, 2020). UNESCO reported to mitigate virtual and remote learning resources for ensuring the continuity of learning in student community (Ali, 2020).

Even prior to COVID-19 outbreak, growing demands in integrating technology into classroom scenario occupied a milestone in educational transformation and understanding the behavioral intention of teachers and students for adapting the technology based education is a major determinant (Joshi et al., 2020).One of the major challenges in this technology-driven scenario is to provide meaningful learning experiences and to apply acquired knowledge to solve real-world problems (Singh, 2016). Effective strategic planning emphasizing on collaborative framework on learning, project-based learning and problem-solving skill acquisition learning through online instructions and solving related pedagogical issues were at higher priority. Studies had reported increased effectiveness and efficiency of e-learning with minimum connectivity issues in teaching–learning process. There were many theoretical models for integrating technology into educational settings, for empirical analysis of technology acceptance by estimating infusion and adoption level of new information system (Rowe, 2018). Technology Acceptance Model (TAM) was used as an idealist construct for predicting users' acceptance of technology in terms of perceived usefulness, ease of use, attitude towards computer use and behavioral intention to use computer by user-end (Fayad & Paper, 2015; Masrom, 2007). Social psychology based theories such as the Theory of Reasoned Action (TRA) and the Theory of Planned Behavior (TPB) were also documented to investigate the behavioral dimensions of information and technology usage (Hamiza et al., 2020; Ozer, 2011).

Even though, delivering theoretical concepts were broadened beyond classroom walls and well adapted with e-learning scenario, there were great uncertainties in providing laboratory experiences for tertiary education especially in STEM disciplines, owing to stress and anxiety in the academic field. Government of India's Virtual Laboratory Project added a new dimension to the web-based digital learning intended with individualized learning and higher degree of flexibility for providing practical skills of science for analyzing scientific data (Diwakar et al., 2010; Nedungadi et al., 2011). Learning Management Systems (LMS) in the N-tier architecture enabled to plan and implement modules for academic courses and to assess learning process or outcomes through learner enrollment, reports and various assessment strategies. ICT enabled virtual laboratories offers a laboratory platform for undergraduate and postgraduate science and engineering education, with animated experimental protocol, simulated replica of real-life experimentations and remotely controlled laboratory equipment for executing experimental practice at zero cost (Diwakar et al., 2014). As part of Ministry of Education initiative, over 43 virtual laboratories with more than 360 multimedia rich experiments were developed on various disciplines of science and engineering education. The user-centric approach in visualized online experimentations with animation, simulation and remote triggered experimentations marked in behavioral assessments of user's skill development and perception of laboratory experiences as outcomes of technology usage (Diwakar et al., 2016). We also commenced an effort for developing existing experiments that were using outdated technologies are being converting to HTML5 to make them mobile-compatible and user intuitive.

Previous studies on perceptions of technology adoption based on TAM model for usage analysis on virtual laboratories on social, cognitive and teaching presence indicated virtual laboratories as a new pedagogy for complementing laboratory experience (Cheung & Vogel, 2013). Literature surveys indicated virtual laboratories as an education platform for augmenting user engagement and critical thinking in a blended learning scenario for enhancing tertiary education in rural India by disseminating laboratory education ubiquitously to geographically and financially challenged institutions (Diwakar et al., 2016; Radhamani et al., 2015). Integrating ICT enabled education platforms to have shown to enhance cognitive learning, memory retention and reflective thinking of student community. In a teacher perspective, it has been reported that blending virtual laboratory usage in the curriculum has driven to reduce cognitive load on teachers supporting the self-organized learning of students with minimum involvement instructor dependency (Radhamani et al., 2014; Achuthan et al., 2017). In this technological era, it has shown to extend the scope of traditional laboratory education with respect to access time and costly equipment sharing with in a larger pool of user community. Nowadays, strategies for facilitating adoption of technology enhanced e-learning and distance learning have been thought to be a functional attributes of educational administrators (Maslin, 2010). According to Innovation Diffusion theory, perceptions of a technological innovation were quantitatively measured by the constructs namely relative advantage, compatibility, complexity, trialability and observability. Virtual laboratory platform was designed as user-interactive content rich material by emulating the experimental protocol with click gestures for providing an actual feel of laboratory experience (Diwakar et al., 2019). Simulated mathematical reconstructions of real-life datasets and biochemical and biophysical approximations of biological datasets facilitated user interactions for improving user engagement. Remote authentications to costly lab equipment were also an added advantage for intended user community where the equipment was managed by lab servers and user authentication and access were moderated by service brokers (Kumar et al., 2014). Pedagogical research on the perception of virtual laboratories in classroom education indicated potential adoption of media rich virtual laboratories based on TAM, OER and Rogers' Innovation Diffusion Theory (Achuthan et al., 2020; Radhamani et al., 2018). Studies on student-centered approach on learning indicated constructivist thinking and active experimentation through online mode supporting the role of virtual laboratories in guided inquiry model and Inquiry-based learning approach. Learning Management System (LMS) of virtual laboratories provided an easy platform for the teachers to conduct examination and evaluate students on the basis of their online performance

(Rapuano & Zoino, 2005). Nodal center initiative among university teachers supported the adoption of innovative technology for sharing within the user community.

The objective of this paper is to understand social and behavioral interaction among adopters of virtual laboratories; teachers and students, in the context of an Indian education system using ICT tools. In this technology innovation time domain, the study explores the perception of virtual laboratories in classroom scenario using push–pull mooring effects as well as analyzing the role of technology mediated virtual laboratories a potential probe for acquiring laboratory skill training during COVID-19 shutdown days.

1.1 Role of virtual laboratories in laboratory skill training during COVID pandemic

Due to the rapid spread of COVID-19 and the delay in finding vaccine, prompted online mode of learning strategy during the odd semester of the academic year 2020–2021. Even though, theory classes were conducted online, education institutes were still facing problems in conducting laboratory classes which were integral component in engineering and biosciences disciplines, causing extreme stress and anxiety in the academic world (Almaiah et al., 2020). These virtual laboratories have been used as a complement learning resource to in-person laboratories for both teacher and students since the early 2000s (Vasiliadou, 2020). There have been efforts to estimate how effectively virtual laboratories could be utilized for overcoming difficulties of laboratory course (Mishra et al., 2020). Recently, in order to assess the learning level of virtual laboratories among mechanical engineering discipline, a faculty development program was conducted among teachers of mechanical engineering, who then trained students in fluid mechanics virtual laboratories (Kapilan et al., 2021). Majority of teachers supported role of virtual laboratories in enhancing their teaching skills and helping students to complete their laboratory practices without affecting the quality of learning. Another study indicated changes in traffic patterns due to lockdown measures and the rapid switch to online e-learning collaborative platforms. It was observed that traffic for online learning had doubled to cope up with social distancing in classroom education (Favale et al., 2020; Vasiliadou, 2020). Universities in India and abroad have been implementing virtual laboratories based online examination platforms for not delaying semester laboratory examinations (Ray & Srivastava, 2020). Augmented usage of virtual education tools in colleges and universities have attributed to the pandemic lockdowns.

1.2 Exploring learner's intention on usage of blending learning approach: A perspective on analysis of diffusion theories and learning models

The increasing popularity of virtual classrooms or online platforms in the COVID pandemic shared learning interests for improving interpersonal communication and relationships thereby engaging learning process (Gamage et al., 2020). Like traditional classroom education, social networks contribute to implicit and explicit knowledge transfer for encouraging innovation and attaining professional knowledge through real time feedback. Understanding the methods for adoption of innovations in mainstream academia has a marked influence in social, cognitive, and contextual aspects of technology acceptance. Several models characterizing diffusion, acceptance, and adoption of innovations exists attributed to behavioral change in adoption decisions.

According to Rogers' Innovation-Diffusion Theory (Rogers et al., 2019), innovation-decision process is multifaceted with information-seeking and information-processing pipelines followed by adoption of innovation by the stakeholders. Analysis of Roger's innovation diffusion theory on acceptance and implementation of virtual laboratories (Achuthan et al., 2020) indicates the process dynamics between innovators and adopters with the notable qualities relative advantage, compatibility, complexity, trialability and observability by interconnecting technology, social interaction, and communication channels (Helitzer et al., 2003). Concerns-Based Adoption Model (CBAM) comprehends changes in terms of technology (Newhouse, 2001)depending on teacher's adoption in innovation attributed to change in curriculum. Widely employed models in education research (Lai, 2017)were Technology Acceptance Model (TAM) and the Universal Technology Adoption and Use Theory (UTAUT) focusing on to answer questions related to technology adoption (Straub, 2009) among student teacher community for providing statistical evidence of innovation adoption in curricula(Talukder, 2012; Tarhini et al., 2013). Applying learning style theories in pedagogic concept has brought multiple dimensions in categorizing learning strategies, although such studies on laboratory skill education are limited. Kolb's Experiential Learning Model (Kolb, 1984) has been widely accepted as an efficient pedagogical model of learning. Studies indicated virtual laboratories with pre- and post-lab sessions were associated with Kolb's cycle to facilitate constructivist learning (Diwakar et al., 2018).

Even though, literature addressed concepts of social learning (Hamiza et al., 2020)and adoption-diffusion theories (Penjor & Zander, 2016), only some have empirically examined switching behaviors of users with respect to technology substitutes. In a learner perspective, switching is a type of migration behavior between learning platforms. Push–Pull-Mooring (PPM) model, a basic framework for migration research determines migration behaviors by providing useful insights of shifting paradigms on various social-networking areas (Hou et al., 2014). Push effect is related to the factors or perceptions pushing away from the origin and pull effects attract the users to migrate to a newer destination while mooring effects are situational factors facilitating the migration. A study on switching intention of users indicated social interaction and service quality as push effects, switching costs and prior switching experience as mooring effects and attractiveness of new services and social effect as pull effects on Social Network-based Learning Platforms (Liao et al., 2019). Another study on Factors Affecting Individuals' Switching Intention to augmented or virtual reality indicated personal innovativeness as mooring effects with interactivity, experience ability, enjoyment as pull effects and low usefulness, functionality, simplicity, and perceived inefficiency as push constructs (Diwakar et al., 2014). A model for virtual laboratories in STEM education with push–pull mooring theory (Liao et al., 2019) was proposed and depicted (Fig. 1).

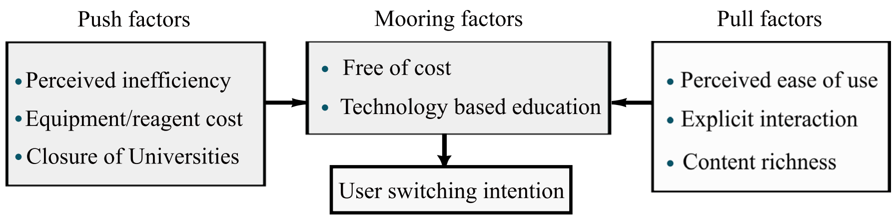

Fig. 1 Factors based on push–pull mooring theory and virtual laboratory usage. This model was used to assess factors that affected virtual laboratory usage and adoption

In the current environment filled with challenges at various levels of the education system, shift from face to-face instruction to online instruction needs to strengthen the research model in switching intention of user community world-wide.

A key element for enhancing university level education in biosciences is the need of time and expertise for familiarizing laboratory skill training apart from regular theoretical knowledge (Sridharan et al., 2016). Studies on usage of virtual laboratories among student–teacher communities indicated guided and autonomous methodological approach for adaptive learning process in a blended classroom environment (Diwakar et al., 2019). Usage analysis with remote and distant learners indicated the adaptability of such learning platforms in overcoming the classroom-based education limitations and the usage of virtual laboratories as next generation interactive textbook for blended and remote education (Sasidharakurup et al., 2015). A study had looked into the potential of using computational aspects, mathematical modeling and biophysics with explicit user interaction for integrating exhaustive models for larger framework in the biological models and processes (Nizar et al., 2017). A previous study reported the role of blended approach in reducing instructor dependency for promoting user centric self-learning pedagogy for complementing skill training in biosciences and engineering education disciplines (Diwakar et al., 2015).

2 Methods

The virtual laboratories used in this study were hosted as a Platform as a Service (PaaS) and are freely available (http://amrita.vlab.co.in/). The term 'virtual laboratory' here refers to a collection of online experiments deployed for all students and educators who register on the platform with their email ID. The laboratories are in various disciplines of STEM and most of the tests were among undergraduate learners.

2.1 Validation of students' acceptance of virtual laboratories in education – questionnaire based analysis on TAM model

Based on social cognitive theory and decision-making theories, Davis' Technology Acceptance model (Lederer et al., 2000; Fetscherin & Lattemann, 2008; Lai, 2017) described how an individual's perceptions of a technology innovation affect the eventual use of that technology. This study was based on information technology acceptance research utilizing technology acceptance model. It employs user acceptance, emphasizing on perceived ease of use defined as "degree to which a person believes that using a particular system would be free of effort and perceived usefulness, defined as "the degree to which a person believes that using a particular system would enhance individual performance.

For this study, a survey-based analysis on experiential learning using virtual laboratories were conducted in 2019, among a group of undergraduate and postgraduate students (N = 1059) of an Indian institution, where virtual laboratories were implemented as a curriculum material in their academic process. Of the participants, 54% were male 46% were female and their ages ranged between 18 to 26 years. In the initial phase, the students were introduced into the fundamental laboratory concepts through virtualization techniques with the help of an instructor. Later, the study participants integrated virtual laboratory topics to assist conceptual and experiential learning for their academic achievement. Feedback data regarding the acceptance of technology-based laboratory education were collected after the successful completion of their semester system. Assessment data was not specified for a single laboratory experiment but for a set of laboratory modules completed in that specific time interval. Students spent approximately 2 h interacting with equipment and laboratory protocols and training on the online experiment. The feedback questions were focused on transformation, change in user behavior when migrating from a textbook oriented learning to a visualization-based interactive learning platform; augmentation, technology-based adaptation in learning along with their conventional learning for improving skill sets and substitution, as user intention to prefer virtual laboratories as supplementary tool for laboratory courses, with easy access beyond the classroom hours (Table 1).

The usage time and user access time graphs were also analyzed for testing the adaptability of virtual laboratories in education. Push–pull mooring effects on transforming education perspectives were also analyzed with the questionnaire feedback session.

2.2 Analyzing the perception of virtual laboratories in exploring practical skills in STEM education during COVID-19 pandemic

For interpreting the utilization of virtual laboratories during this lockdown phase, the study focused on monitoring the online usage statistics of virtual laboratories by university teachers and students all over the world. The quantitative analysis started after COVID-19 pandemic (January 2020 -December 2020) due to COVID 19 (post-covid). The analysis focused on page views, instance of users visiting a virtual laboratory page, new user registration indicated users registering to access the laboratory material and feedback sessions, critical element for developing and deploying the user-friendly platform. Data traffic in using virtual laboratories was compared with before COVID-19 time period, January-December 2019.

Table 1 Technology Acceptance Model questionnaire for evaluating usage of virtual laboratories across criteria

Sl.No	Role of virtual laboratories in education	Feedback Questions
1	Transformation	Q1. I prefer to use virtual laboratories like I use textbook, when I do not have instructor support Q2. Virtual laboratories help me understand key questions related to the concepts Q3. In the presence of a teacher, virtual laboratories help me understand experimental concepts better (minimal instructor support) Q4. I prefer animations more than mathematical simulations while using virtual laboratories Q5. Animations in virtual laboratories represent what I see in a classroom laboratory environment Q6. It is difficult to use virtual labs without expertise in computer Q7. Will virtual labs replace real lab?
2	Augmentation	Q1. Virtual laboratories help me to learn: Concepts, Procedure, Both concepts and procedure Q2. Based on your experience with virtual laboratories, how would you use virtual laboratories in your learning process? Q3. Virtual laboratories helped me in learning practical aspects of equipment, laboratory experiences and analysis of results
3	Substitution	Q1. Explicit user interactions, like clicking at certain points, keep me focused on the experiment Q2. Simulations help to apply theoretical knowledge into practical experience Q3. Usage of virtual laboratories helped me to reduce time spent in learning experiments when compared to physical laboratory practices Q4. According to your point of view, do you think virtual laboratories helped student communities (below average and/or above average students) to score better in examinations

3 Results

Assessments to test the role of transformation, augmentation, and substitution of virtual laboratories in the current higher education scenario were analyzed based on usage. Cronbach alpha value was calculated as greater than 0.80 for all the tested variables.

3.1 Transforming conventional education with minimum instructor dependency using blended approach before COVID-19 days

Analyzing feedback responses (Fig. 2), there was more positive responses from users and the data showed that more than 90% of users either strongly agreed or readily agreed that 1) the platform was useful as interactive textbook in the absence of instructor 2) to understand experimental concepts with minimum instructor support 3) visualization as a tool for understanding experimental techniques and protocols 4) Reproduced real laboratories in a user-interactive way and 5) to understand conceptual learning with minimal supervision from teachers. Moreover, the data showed that more than 80% users strongly disagreed or disagreed for the facts 1) the platform replaces traditional laboratory techniques and 2) perceived usefulness of virtual laboratories without basic proficiency in computer usage.

3.2 User adoption promotes skill training and problem-solving skills in laboratory education

In the quantitative study, 27% students indicated virtual laboratories in learning experimental concepts and 13% indicated the role of virtual laboratories in learning experiment procedure. 60% of participants indicated role of virtual laboratories in augmenting conceptual and experimental learning (Fig. 3A). Also, 24% of students indicated they used virtual laboratories as a pre-lab material, 19% indicated virtual laboratories as a post-lab material, 21% indicated they used virtual laboratories as

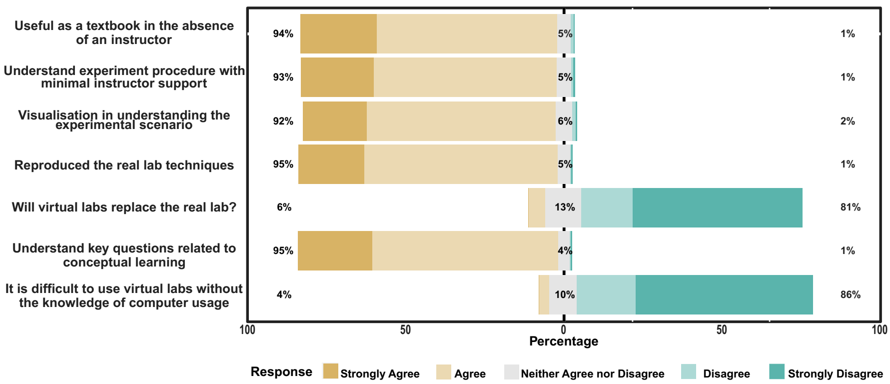

Fig. 2 Feedback analysis testing transformation of education using virtual laboratories

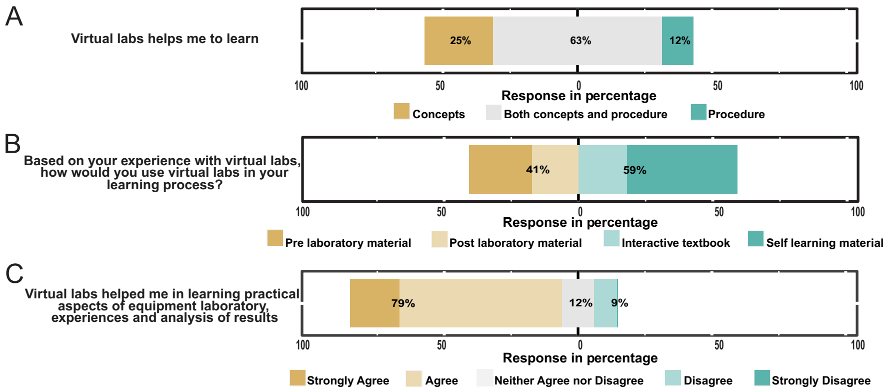

Fig. 3 Feedback analysis on augmented usage of virtual laboratories in conventional learning

interactive textbook for laboratory module while 36% indicated it as a self-learning material for improving their laboratory skills as that of conventional classroom education (Fig. 3B. 94% of the participants indicated virtual laboratories as a platform for conceptual training related to costly laboratory equipment (Fig. 3C).

3.3 Explicit user interaction substitute's real-life experimentations with ICT enabled virtual laboratories

90% of participants indicated role of explicit interactions in engaging laboratory experiment and supported the role of user-centered simulations in applying theoretical knowledge into experimental practice for enhancing skill education. Participants also reported reduced time for learning the experiment when compared to a conventional laboratory setting. Students also supported that with the integration of virtual laboratories, they have performed better in the examination aiding in academic achievement (Fig. 4).

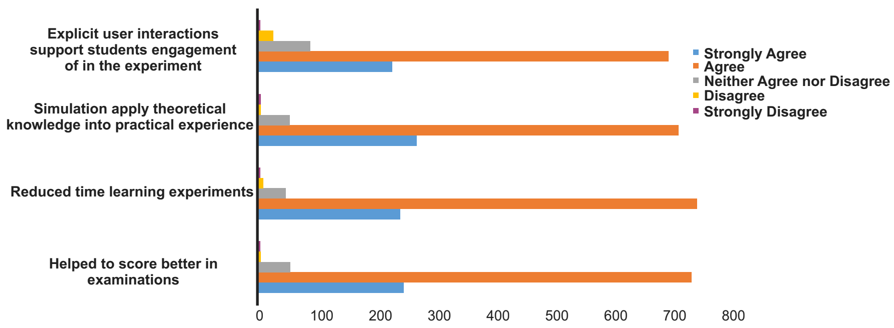

Fig. 4 Feedback analysis on virtual laboratories with explicit user interaction

3.4 Users behavior as assimilators with reduced usage time-user access time bins

Among the participants, 20% indicated they have accessed a single module of experiment only once for learning both theoretical and experimental concepts. 54% indicated, they accessed less than five times to learn an experiment while 26% indicated they accessed virtual laboratories for more than 10 times in a week for learning the experiment module without an instructor's support (Fig. 5A). Most students in the study were assimilators (60%), 20% favored to be divergers, focusing on details of the experimental process while few students were convergers or accommodators (Fig. 5B).

3.5 Global usage of virtual laboratories increased during COVID-19 lockdown phase

Online usages data 2019–2020, exhibited an observed rapid increase in the number of registered online users with the lockdown phase (Fig. 6). Documented online feedback also showed that the virtual laboratory platform has been used by students and teachers worldwide to fill the large gap seen in laboratory education in the current scenario.

Reduction in the usage on the month of June and July was due to academic holidays in semester during university education (Fig. 6A, B) which was increased in end of the year 2020. Mapping the analytics for COVID-19 cases as per WHO report and comparing it with the virtual laboratories' usage index showed 63% correlation between numbers of virtual laboratory users per month on the virtual laboratory platform with number of new cases reported per month (Fig. 6C).

The findings correlated with similar studies on statistical analysis of virtual laboratories (Achuthan et al., 2020). The curve of virtual laboratories adoption among students-teacher community had a logistic 'S' shape, with an early slow phase, a rapid middle phase with widespread, and a slow third phase with an incomplete

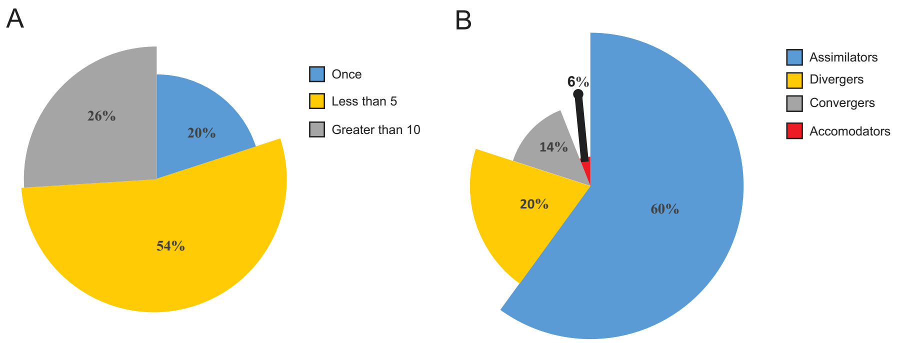

Fig. 5 Analysis of user behavior, usage time and access among virtual laboratory users. **A.** Number of usages per week. **B.** Learner types based on Kolb's learning styles

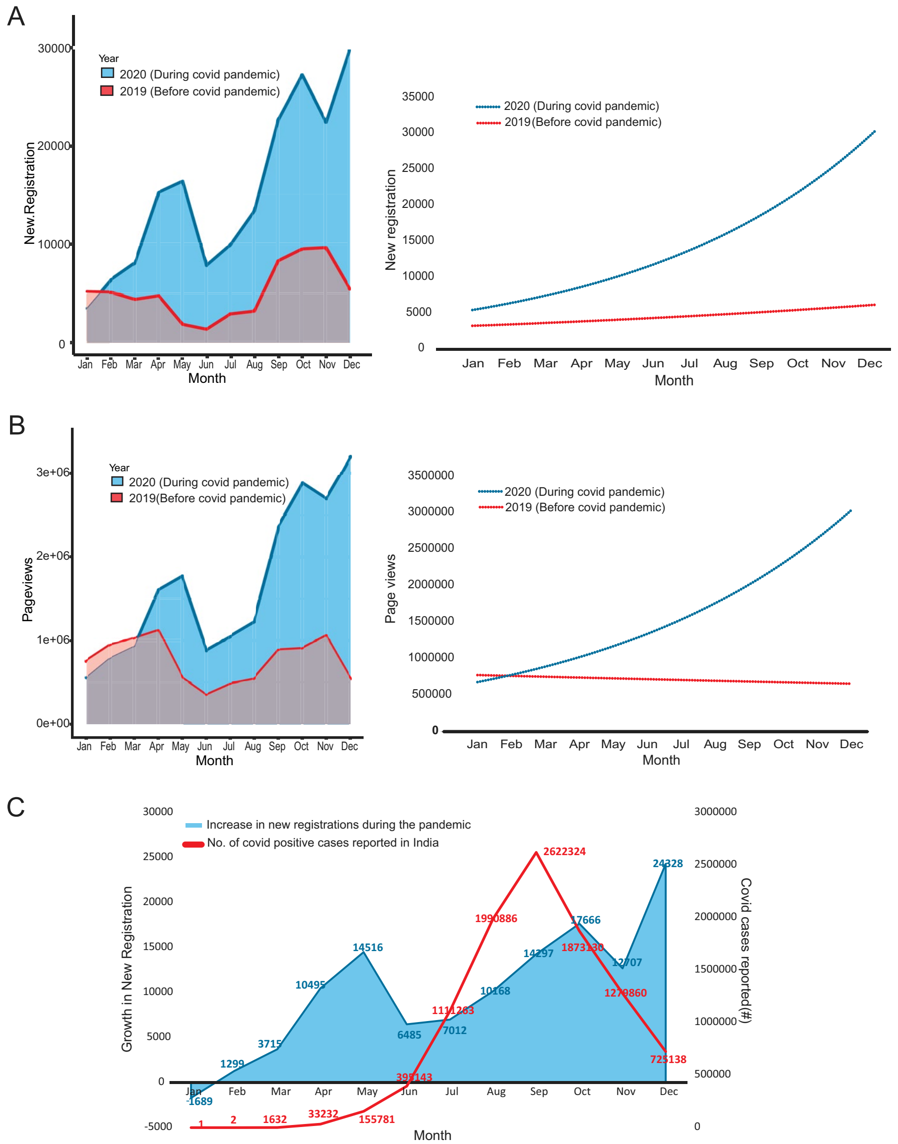

Fig. 6 Usage of Virtual Laboratories before covid and during-COVID-19 (post COVID-19) lockdowns. **A**. Comparison of usage index of virtual laboratories before (2019) and during (2020) COVID-19 pandemic. **B**. Trends in the usage of virtual laboratories in as indexed as Page views in virtual laboratory platform **C**. Google analytics for virtual laboratory users and COVID-19 data statistical data as per WHO report

penetration in the end. While assessing the current usage trends of virtual laboratories with diffusion based-Bass model, the trend suggests virtual laboratories will have 2 million users by 2031.

3.6 Users intention to switch to online education from offline conventional classroom education based on push pull mooring theory

The summary of data regarding online perceived usefulness of virtual learning platforms from undergraduate and postgraduate students of bioscience discipline is tabulated (Table 2).

Data showed users' intention to switch from traditional classroom-based learning to online interactive platforms for enhancing laboratory education. Push factors included perceived inefficiency, inability to conduct regular classes, difficulty in assessing laboratories while the pull factors were ease of use, user interaction and adaptability to laboratory content on the virtual laboratory platform. A high percent found cost effectiveness and technology in education as mooring factors. The users' intention to transform traditional education paradigm to a virtual learning platform for providing laboratory training amid lockdown issues seemed pertinent (Fig. 6).

4 Discussion

Exploring the perception of virtual laboratories among intended user communities, this study focused on analyzing the impact of technology-based innovations in extending laboratory education within the context of COVID-19 outbreak scenario. In the absence of face-to-face classroom teaching, these virtual laboratories were perceived and used as Massive Open Online Courses (MOOCs) where the role of the instructor was reduced, and training experience oriented towards participation and practice of the designed online experiment. This quantitative case study provided insights for the usage and adoption of e-learning tools and virtual laboratories for laboratory skill training needs of tertiary education. This study investigated how virtual labs were implemented as a learning element for tertiary education before-covid (2019) and after covid days (March 2020 onwards). Results indicated virtual labs as a substitution for instruction and demonstration phase of conventional laboratory classes, more effectively reducing the instruction dependency. Studies reported how virtual laboratories catalysis to enhance student's autonomous learning

Table 2 Analysis of push–pull mooring effect on virtual laboratories usage

Analysis Factor	Factors in research question	Percentage of users	Cronbach's alpha
Push Factors	Perceived inefficiency	75	0.89
	Difficulty in accessing laboratory equipment and reagent-economic analysis	88	
	Lack of regular classes	86	
Pull factors	Perceived ease of use	93	0.82
	User interaction	90	
	Adaptability to laboratory content	95	
Mooring factors	Cost Effective	98	0.84
	Merging technology-based education	92	

and self-learning approaches in a blended classroom scenario. Utilization of virtual labs in procedure based and concept-based learning proven the ability of students to improve their problem solving and analytical skills. The user-interactive platform in virtual laboratories has provided learner satisfaction in laboratory skill training with a blend of theory and practical approach. The research findings were in accordance with a study reported the role of virtual labs in improving students solving skill in physics and biology course (Gunawan et al., 2018; Syahfitri, 2020). Usage analysis had reported a model of laboratory education by applying Kolb's experiential learning theory for understanding the learning styles of users from diverse regions and to examine how users perceive and process information through different stages of learning. Our results indicated 60% of assimilators in this virtual lab-based study, where the learner's approaches reflective observation for building theory based on experimental scenario followed by abstract conceptualization for attaining conclusions based on the theoretical concepts.

User responses relating to learning of experimental framework and conceptual understanding with minimum instructor support suggest virtual laboratories seem to be an alternative for laboratory education for distant learners especially during this after COVID-19 scenario and in absence of instructor-led physical classrooms. Technology Acceptance Model (TAM) based questionnaire feedback were employed for testing transformation of education into e-learning platform, augmented use of virtual laboratories as supplementary education material for laboratory modules and substitution of visualization techniques for fulfilling the requirements of laboratory education. Through the analysis and surveys, this study looked at the switching intentions of learners using a virtual learning platform for laboratory education. The real-world push–pull-mooring (PPM) model may explain the migration behaviors of learners in online interactive learning environments and may allow educationists to weigh on features that may empower better educational strategies. The push–pull factors may vary before and during the COVID lockdowns but factors like perceived ease of use, cost effectiveness may drive the usage higher even later. This may suggest the use of virtual laboratories may keep increasing even after the lockdowns may be shifted.

Post-usage survey among student users indicated its role in aiding conceptual and experimental learning suggesting inquiry based and guided education with minimum instructor dependency, which is critical especially since online classes have limited direct interactions. Studies indicated the use of virtual laboratories as effective for training with sophisticated instruments that were not available during remote education thereby improving concepts behind practical skillsets beyond the walls of a traditional classroom scenario. Most students finished a laboratory module in less than 1 h that would not be possible in the real laboratory, suggesting the efficiency of virtual laboratories as practice tools. Usage time and user access plot indicated repeated usage of virtual laboratory content by students suggesting perception of laboratory education without loss of costly reagents or chemicals. Students also reported multi fold advantages of visualized experiments as pre-lab material, post-lab material, interactive textbooks, and self-organized learning platform, thus extending the need of integration of virtual laboratories in this challenging time, as supported by this and our previous studies. Analysis of online usage statistics of virtual laboratories even after shutdown of schools and universities indicated utilization of e-resources and available online platforms for spreading high-quality laboratory education amid lockdown days. Beyond classrooms, adoption of technology-based education may be crucial for productivity in the context of do's-and-don'ts of physical laboratories recreated on a distant or remote education platform to cope up with social distancing matters attributed to COVID-19 lockdown. An increased trend of usage in the month of March, April and May 2020 were indicative of university exams and the subsequent usage of virtual laboratory platforms for conducting online laboratory examinations, although it was not known in which all institutions or professors employed the platform for examinations since the platform is freely available on the web for all to use. In 2020, usage statistics of August and September compared to June and July month may be attributed to the usage of virtual laboratories in the curriculum for conducting online laboratory education in Indian universities. With the plethora of challenges facing in education sector post COVID-19, similar studies were also reported on transformation of traditional classes to online delivery considering potential impacts on learning experiences on student communities (Babinčáková & Bernard, 2020; Gamage et al., 2020).

Usage statistics alone may not predict the aspects related to learning, and yet it described how virtual technologies can remarkably be a unique solution for ensuring equity in distant education through internet and technology based education at home. As, assessment is the potential intrinsic factor for measuring knowledge level, practical skills and learning abilities of a student, and since COVID-19 is still in the second half of the battle, future works will explore data from formative assessment, continuous evaluations and summative assessment of mid or end semester examinations for evaluating behavior analysis of students before COVID-19 and after outbreak of COVID-19 timelines.

The findings presented in the study were based on data collected from university students of similar age, and yet the behavioral and switching intention of technology-based education vary with learners in different age groups, which was not the context for this study. Further, behavioral studies were based on social cognitive theories that included the assessment of the cognitive modes in education among distant learners for identifying the impact of virtualizations techniques as a substitute for classroom education post-COVID-19. Although, this study was posed from both classroom and online perspective, it may be essential to quantify learning ratio among larger populations of subjects with different subsets of STEM discipline learners for getting a generalized understanding of how virtual laboratory components enhance skill training and problem-solving skills with minimum instructor support during COVID-19 imposed shutdown.

5 Conclusion

Laboratory education in STEM disciplines plays an important role in the overall professional and academic achievements students. Although, online learning during COVID-19 has added a sense of uniformity for many learners across the globe, laboratory skill training attempts to incorporate various usage and pedagogical modalities within online education towards favoring reliable learning outcomes. While before and post-COVID-19 may be perceived as two crucially different phases by educationists, post-COVID-19 study on these virtual laboratory usages reveals these novel trends on adoption of ICT tools may be based on online learning behaviors observed even before the lockdowns. It may be suggested that new tools should rely on outcomes from studies on remote and blended education while targeting learning objectives. Other studies with online users may be needed for assessing duration, reflective learning, biases, and disadvantages. This study could be extended towards understanding the challenges that impede in successful implementation of e-learning systems and tools during COVID-19 pandemic.

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