The VLAB OER Experience: Modeling Potential-Adopter Student Acceptance

Raghu Raman, *Senior Member, IEEE*, Krishnashree Achuthan, Prema Nedungadi, *Member, IEEE*, Shyam Diwakar, *Member, IEEE*, and Ranjan Bose, *Senior Member, IEEE*

***Abstract*—Virtual Labs (VLAB) is a multi-institutional Open Educational Resources (OER) initiative, exclusively focused on lab experiments for engineering education. This project envisages building a large OER repository, containing over 1650 virtual experiments mapped to the engineering curriculum. The introduction of VLAB is a paradigm shift in an educational system that is slow to change. Treating VLAB OER as an educational technology innovation, its adoption by potential-adopter engineering students ($N = 131$) is modeled based on Roger's theory of perceived attributes. Regression and factor analysis were used to analyze the data. Results indicate that the attributes of Compatibility, Ease of Use, Relative Advantage, and Trialability significantly influence potential-adopter students' intention to adopt an innovation like VLAB. The study also observed that using OER (such as VLAB) on desktops and low-cost tablets had similar effects in student performance to using physical labs. This has interesting implications for education policy-makers who are looking to reduce the digital divide.**

***Index Terms*—Experiments, Open Educational Resources (OER), simulation, tablets, virtual lab.**

I. Introduction

One of the grand challenges of education, to provide free and open access to high-quality educational content, is being addressed by the decade-old Open Educational Resources (OER) movement. While a number of OER initiatives like MIT Open Courseware (OCW) [1], Open University [2], and CMU Open Learning Initiative (OLI) are fine examples of academic collaboration in developing content for engineering education, almost all of these focus exclusively on the theoretical aspects of the topics taught and neglect the important lab experiences. This paper describes the development, deployment, and scaling of an OER model for engineering labs, as well as the learning outcomes of students who used the OER. The National Mission on Education through Information and Communications Technology (NMEICT) is one of India's largest government-funded initiatives to promote OER to benefit all types of learners and to reduce the digital divide. As part of this mission, the Virtual Labs (VLAB) OER project, focusing exclusively on lab experiences, is a consortium of 12 institutes whose goal is to develop over 1650 experiments across nine engineering disciplines (http://vlab.co.in). Each lab's multiple experiments, remotely interfaced to a variety of equipment, combine animations, interactive simulations, and mathematical modeling of physical phenomena.

Lab experiences are a critical part of engineering education. VLAB, a technology educational innovation that uses animations, simulations, and videos, appears to have great potential to provide these lab experiences in engineering education, but research evidence on the diffusion and adoption of OER for virtual labs is limited. By allowing faster setup time and immediate reporting of results, virtual labs are considered much more efficient than physical labs, as observed in studies related to heat and temperature with undergraduate students [3]. The study reported here investigated potential-adopter students' perceptions of VLAB OER, using Roger's theory of perceived attributes.

Manuscript received May 07, 2013; accepted September 21, 2013. Date of publication February 07, 2014; date of current version October 28, 2014. This work was supported in part by Amrita University and the National Mission on Education through ICT, Government of India.

R. Raman, K. Achuthan, P. Nedungadi, and S. Diwakar are with the School of Engineering, Amrita University, Kollam 690525, India (e-mail: raghu@amrita.edu).

R. Bose is with the Department of Electrical Engineering, Indian Institute of Technology (IIT), New Delhi, Delhi 110016, India.

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TE.2013.2294152

II. Literature Review

A. OER

The MIT OCW project, considered as the pioneer of the OER movement, has over 2150 courses available in multiple languages. More recently, the publication of over 8000 courses online by the international Open Course Ware Consortium (OCWC) indicates that the OER movement has achieved critical mass. A recent phenomenon, Massive Online Open Course (MOOC), addresses the learning needs of tens of thousands of learners at a global level and provides further impetus to the OER movement. A primary argument in favor of OER is that it allows educators to keep current and be flexible in their response to learner needs [4]. On the other hand, OER's enabling of independent learning, without the constraints of institutional organization and structure, could have the unintended consequence of quality assurance issues from the absence of institutional endorsement and accreditation [5], [6].

B. Diffusion Educational Innovation

Several studies offer insight into the factors that influence the diffusion of educational innovation [7]–[10]. In [10], innovation is defined as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption." For students, performing experiments in a physical lab setting is not new, but the VLAB approach to lab experimentation is entirely new. According to [10], it is the "perception" of the potential-adopters that is important; if potential-adopters consider the approach to be new, and then it is indeed an innovation as far as they are concerned. Furthermore, the diffusion of an innovation is constrained by the number of people aware of its existence. However, over time, a "word-of-mouth" information diffusion process brings the innovation to the attention of potential adopters who, in turn, become adopters. This leads to an S-shaped adoption curve: Successful innovation goes through a period of slow adoption before experiencing a sudden period of rapid adoption and then a gradual leveling off.

C. *Virtual Labs for Engineering Education*

Studies of lab experimentation [11] concluded that virtual experiments have a positive effect on students' conceptual understanding of electrical circuits, as measured by conceptual tests. In [12], university students simulating electric circuits with moving electrons were found to have a better acquisition of conceptual knowledge when using the virtual approach. The results of [13], examining students' experience of using virtual labs in an undergraduate chemistry course, indicate that perceived enjoyment, motivation, and the actual experience of using the labs are positive factors for its adoption. In [14], using 3-D effects, students were found to exhibit much better familiarization with the lab settings for the experiments in the case of the virtual lab than they did with the physical lab. Studies by [15] also support the view that virtual labs enable students to use complex inquiry approaches to separate variables that otherwise might be difficult in a physical lab setup. Interestingly, [16] observed that engineering students who operated under a blended model combining both physical and virtual labs had better learning outcomes on the conceptual and procedural knowledge of electric circuits than when they used only physical labs. An in-depth study on the development of VLAB [17], [18] showed how diverse areas of engineering, which may be either protocol intensive or computationally demanding, could be incorporated into VLAB.

III. About VLAB OER

A VLAB consortium was formed with 12 top-ranked institutions focused on engineering education strategically located across India. These 12 partner institutes are opinion leaders and are considered much more innovative than the colleges in their vicinity, their followers, some of whom became VLA Nodal Centers (see Section III-B). With over 120 Nodal Centers signed up, the authors believe the opinion leadership approach has been effective in bringing about behavior change in colleges' VLAB adoption. The OER approach to VLAB development was discussed with the partners' institutes, and it was decided that content would be released under Creative Commons Attribution, a noncommercial distribution model. Nine engineering and science disciplines were targeted, with 1650 experiments chosen, as shown in Fig. 1. A two-level leadership approach was taken to managing the project. First, each partner institute nominated a Principal Institute Coordinator (PIC) responsible for the deliverables from that institute. To ensure high quality and consistent subject matter for each discipline, a Discipline National Coordinator (DNC) was appointed, responsible for all labs in the discipline across multiple partners. Since 2011, the VLAB OER has developed considerable momentum; there are over 19 000 registered users of VLAB, 35% of them outside India; see Fig. 2.

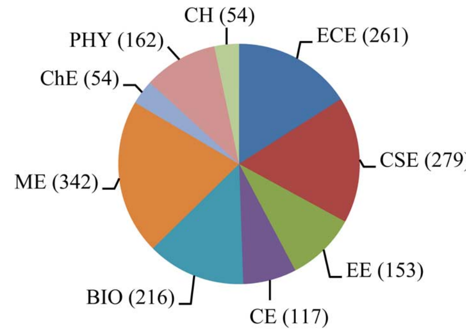

Fig. 1. Distribution of experiments by discipline (ECE—electronics and communication engineering; CSE—computer science and engineering; EE—electrical engineering; CE—civil engineering; BIO—biomedical and biotechnology; ME—mechanical engineering; ChE—chemical engineering; PHY—physics; and CH—chemistry).

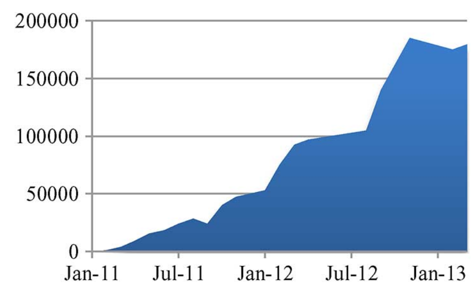

Fig. 2. Number of visitors to the VLAB portal.

A. *VLAB OER Content Development Model*

A multidisciplinary lab team of subject-matter experts, instructional designers, graphic designers, animation experts, and software developers was assembled to build the labs. Most faculty members who contributed to this project were academics who held teaching responsibilities. Every DNC had to conduct a quarterly review of the labs developed with a review committee consisting of experts from academia and industry. One of the unique aspects of VLAB was that it brought together partners with different technological and cultural horizons. A VLAB Collaborative and Accessibility Platform (VLCAP) was designed [19], shown in Fig. 3, to provide learners with a consistent, homogeneous, and rich interactive experience and to optimize the cost of developing and deploying the labs and minimize dependency on IT and programming resources. This platform provided lab developers with easy-to-use authoring tools, preconfigured templates, user management, and assessment modules.

B. *VLAB OER Deployment Model*

A unique approach was developed to deploying and scaling VLAB to colleges across the country, using a concept of Nodal Centers with a two-step flow hypothesis, shown in Fig. 4. In the first step, based on the concept of interpersonal influence as a factor in the diffusion of innovation, each partner institute conducted hands-on workshops for faculty from Nodal Centers

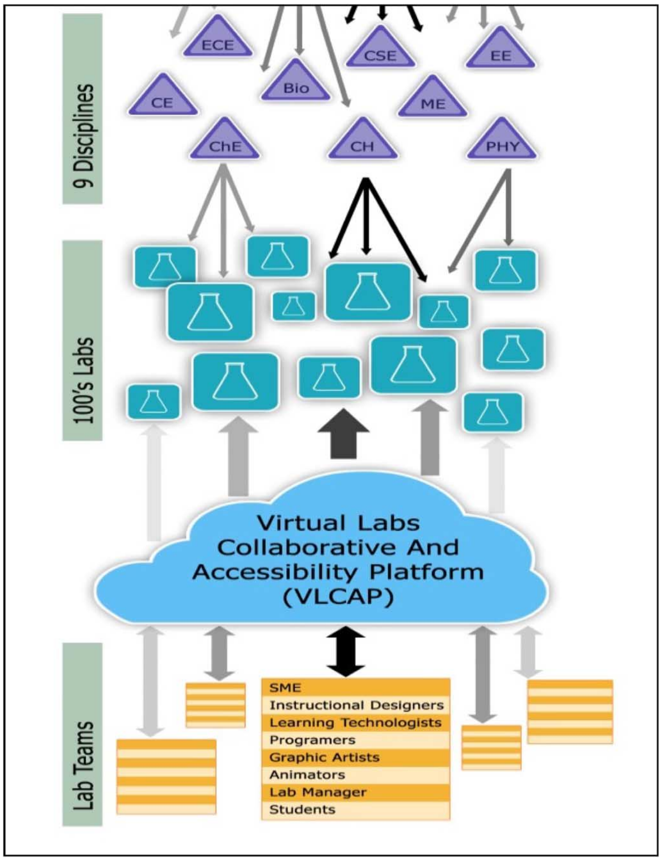

Fig. 3. VLAB OER content development model.

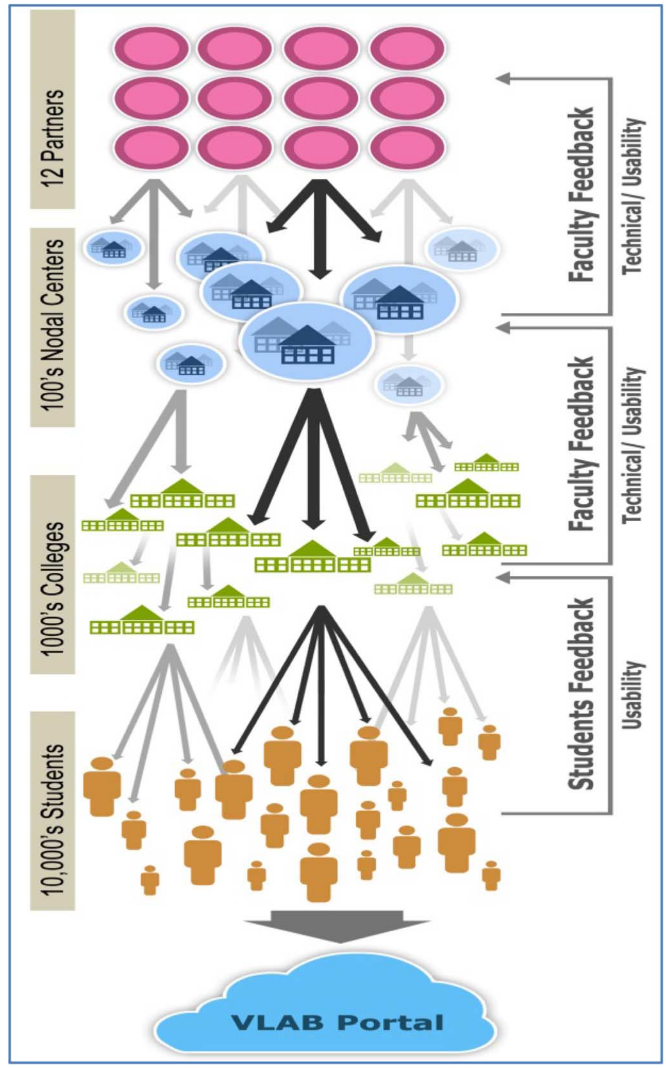

Fig. 4. VLAB OER deployment model.

in their vicinity, showing them how to use and integrate VLAB into the curriculum and more importantly how to conduct the hands-on workshops themselves. The diffusion process starts with a workshop, which explains the concept of the VLAB project and provides an overview with hands-on demos. After the workshop, an expression of “buy in” is sought, to ensure a basic level of commitment in terms of usage and availability of infrastructure, i.e., computer labs. Those who qualify are declared Nodal Centers, and two Nodal Center Coordinators are selected from each Center for liaison. Extensive on-site training and on-site workshops follow. Nodal Center Coordinator meetings are held regularly for the exchange of ideas and for discussions. In the second step, each Nodal Center in its turn trains several colleges in its vicinity, this time focusing more on the students. The interactions between the partner institute and Nodal Centers, Nodal Centers and colleges, and finally between colleges and students created a very healthy feedback loop ecosystem.

Over 56 hands-on workshops were conducted in over 200 colleges. More than 1200 faculty members and over 50 000 students were trained during these workshops.

C. Building Scientific Experiments in Electrical Engineering

Articulating the pedagogical and didactical objectives of an experiment is the first step in building a virtual laboratory experiment. Virtual lab experiments may fall in one of the following categories: 1) *Simulation-based experiments* that model physical phenomena using their governing equations. In some cases, this may also include empirical modeling of experimental systems based on measured data. 2) *Interactive animation-based experiments* where students build the experimental set up, which enhances their procedural skills. 3) *Remotely triggered experiments* where the students operate real equipment remotely through computer interfaces and compute characteristics based on observed natural phenomena.

Once an experiment’s category is determined, the experimental parameters, physics-based boundaries, interactive features, and the like are defined prior to design. The scientific models governing the experiments, along with measured data that would form their basis, are then integrated in a user-friendly interface. Electrical engineering experiments were built in the following thematic areas: electrical circuits (parallel and series circuits and theorems governing them); magnetic material characterization and determination of charge carrier densities; visualization of crystal structures; and the use of Zener diodes, thermistors, and four-point probes to study various phenomena. The design of experiments is a multistep process, the first step of which is to list the constant and variable parameters needed in VLAB to mimic physical experiments. These parameters are

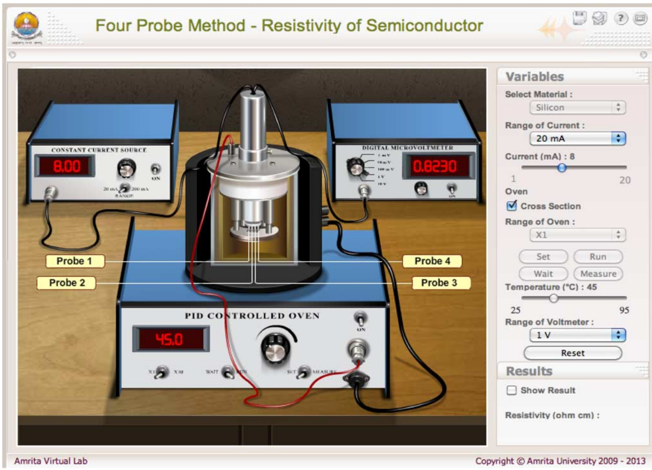

Fig. 5. Sample screenshot of VLAB experiment.

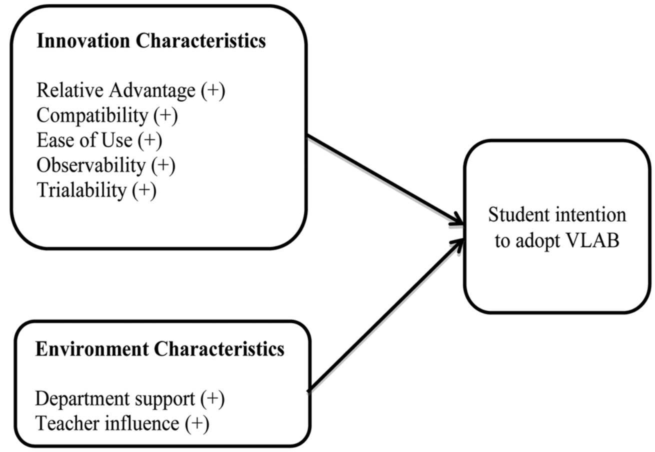

Fig. 6. Research model for VLAB OER adoption.

presented as options that can be architected to be constant or sequentially changing in the experiment. In VLAB, the flexibility to include unobservable factors has a tremendous impact on conceptual understanding. For example, it is impractical to carry out activities such as testing diverse samples, performing experiments in various virtually simulated media, or building complex circuits in physical labs within set lab hours.

The second step is to incorporate factors to promote students' active engagement. These include procedural tasks students must follow to build the experimental set up. Following procedures and making mistakes are forms of inquiry-based learning. Identification of variables and their relationships is an important aspect of understanding the experimental objectives and their application.

The third step is to develop multiple-choice theory-based questionnaires that are administered prior to students' performing the virtual lab experiment to assess their basic grasp of theory.

Finally, a question set is assigned for students to complete as part of their virtual experiment procedure. These questions provide instructional guidance and arouse students' curiosity to explore further. The virtual labs are supplemented by photographic images of equipment, videos describing the process, online help, and links to useful resources.

D. *Semiconductor Resistivity Experiment*

This experiment has students measure the resistivity of a semiconductor like silicon or germanium by measuring the conductivity at varying temperatures; see Fig. 5. VLAB's screen shows the user various components of the experiments such as the cross-sectional view of the oven, the current source, and the voltmeter.

Students' first task is to select the type of semiconductor film and set the temperature of the oven. The indicator on the oven shows the heating rate; once it reaches the set temperature, current is applied to the semiconductor film using two of the four points on the four-point probe, and the voltage across the remaining two points is detected by the voltmeter connected to them. This is repeated for various temperatures and current settings, and the data are plotted on the online worksheet. Students then calculate the resistivity using the sample dimensions provided.

IV. Case Study: Modeling Intention of Potential-Adopter Students to Adopt OER

A. *Research Model and Hypothesis*

In a diffusion model of VLAB, student perception of VLAB was chosen as the dependent variable, and two groups of characteristics—innovation and environment—were chosen as independent variables, as shown in Fig. 6.

B. *Innovation Characteristics*

The five characteristics identified by [10] as having a primary influence on the adoption of an innovation like VLAB are the following: Relative advantage, Compatibility, Complexity, Trialability, and Observability.

Relative advantage is defined as the "degree to which an innovation is perceived as being better than the idea it supersedes" [10]. In this case, students perceived performing experiments with VLAB to be a better approach than using physical labs. Here, the focus is on the potential-adopter students and their perception of the advantages of the VLAB innovation, as opposed to on the advantages proposed by the producer. Compatibility is defined in [10] as the "degree to which an innovation is perceived as consistent with the existing values, past experiences and needs of potential adopters." Compatibility can be explained to be the degree to which potential-adopter students consider VLAB experiences to be consistent with their usual beliefs and values about physical labs. According to [20], perceived compatibility of an innovation has a positive influence on the adoption of that innovation. When potential-adopters find the VLAB difficult to use, there will be resistance to its adoption and usage. Thus, [10] defined the Complexity attribute of innovation as the "degree to which an innovation is perceived as relatively difficult to understand and use." The idea of complexity was formulated from an "ease of use" perspective in this study, whereas the notion of adoption was substituted with the notion of attitude toward use. Trialability is a concept [10] used to describe the "degree to which an innovation may be experimented with on a limited basis." In this case, if potential-adopter students can try the VLAB before fully committing to it, their apprehension of that innovation will significantly decrease. Finally, Observability is defined by [10] as the "degree to which the results of an innovation are visible to others." If potential-adopter students can see the benefits of the VLAB innovation, they will easily adopt it. Often, students are motivated to consider technology innovations promoted by the department head and staff since these will have adequate support resources for training, infrastructure, and so on. In the case of VLAB, students will be positively disposed to adopt VLAB when there is department-level support for the innovation. According to [21], teachers can play a pivotal role in the implementation of an innovation. Hence, potential-adopter students in this study were greatly influenced by teacher support for the VLAB. Based on the general hypothesis that there will be a relationship between student perceptions of VLAB characteristics and their acceptance of the VLAB, the following were predicted.

H1) Relative Advantage has a positive influence on student adoption of VLAB.
H2) Compatibility has a positive influence on student adoption of VLAB.
H3) Ease of Use has a positive influence on student adoption of VLAB.
H4) Trialability has a positive influence on student adoption of VLAB.
H5) Observability has a positive influence on student adoption of VLAB.
H6) Department Support has a positive influence on student adoption of VLAB.
H7) Teacher influence has a positive influence on student adoption of VLAB

C. Research Methodology

The present study conducted hands-on workshops with students, publicized through various media, including e-mail, phone calls, and postal mailing of flyers. Students were selected from various colleges, and a workshop was conducted to raise awareness of virtual labs. Students were first introduced to the virtual labs via an orientation session presentation and a demo. They were then randomly divided into three groups to work on the experiment using desktops, tablets, and in physical labs. All students attempted the same pre- and post-test. The study's research questions were the following.

1) Is there a significant improvement in student performance using virtual labs?
2) How does the performance improvement using virtual labs on desktops and low-cost tablets compare with the performance improvement achieved in the physical lab?
3) Is gender a significant factor in determining performance?

A five-point Likert-scale-based questionnaire with 25 questions was administered to elicit students' perceptions of the factors that influence the adoption of VLAB OER. A total of 131 students (60 female, 71 male) completed the pre- and post-assessments. The survey consisted of seven independent research variables hypothesized to be factors affecting the adoption: Relative Advantage Compatibility, Ease of Use, Observability, Trialability, Teacher Influence, and Department Support.

TABLE I
MEAN AND STANDARD DEVIATION OF ATTRIBUTES

Attributes	Mean	Max	Standard Deviation
Relative Advantage	13.38	15	1.29
Compatibility	8.34	10	1.26
Ease of Use	13.10	15	1.57
Trialability	7.52	10	1.72
Observability	8.73	10	1.01
Department Support	16.14	20	2.84
Teacherinfluence	16.11	20	2.89

TABLE II
SUMMARY OF HYPOTHESIS RESULTS

Attributes		Beta	t-values	Result
Relative Advantage	H1	.213	.174	Accept
Compatibility	H2	.173	.169	Accept
Ease of Use	H3	.446	.544	Accept
Trialability	H4	.226	.177	Accept
Observability	H5	-.032	-.467	Reject
Department Support	H6	.060	.898	Reject
Teacherinfluence	H7	.030	.462	Reject

V. RESULT ANALYSIS

A. Diffusion Survey Analysis

The reliability of the seven attributes had values ranging from 0.65 to 0.86. According to [22], for internal consistency, a reliability Cronbach Alpha value of 0.70 and above is good.

Table I shows the mean results from the survey, indicating the students' high perceptions of Relative Advantage, Compatibility, Ease of Use, Observability, Trialability, Teacher Influence, and Department Influence. The variances for the above variables are low, showing that students had similar perceptions (moderate to high). In order to determine any gender differences in student attitude scores, an independent-samples t-test was conducted; the results are summarized in Table II. In the category Observability ($t = -1.66$, $p < 0.05$) a significant difference is seen between male or female attitudes toward the use of virtual labs. There was no significant difference based on gender in the other groups. Regression analysis was performed using all seven independent variables on the dependent variable intention to adopt.

The stepwise regression results showed that only the attributes Compatibility, Ease of Use, Relative Advantage, and Trialability significantly predicted adoption of virtual labs. The categories Ease of Use ($F = 100.965$, $p < 0.05$), Compatibility ($F = 58.453$, $p < 0.05$), Trialability ($F = 42.750$, $p < .05$), and Relative Advantage ($p < 0.05$) as predictor-variables together predicted 50% of the variation, while the Observability, Teacher Influence, and Department Influence did not have a

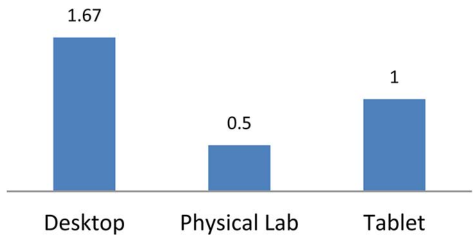

Fig. 7. Estimated marginal means of performance improvement based on labs.

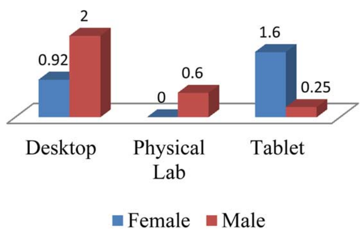

Fig. 8. Estimated marginal means of performance improvement based on gender.

significant influence on the prediction. The β value tells that the Ease of Use ($\beta = 0.446,\ \mathrm{t} = 0.544,\ \mathrm{p} =< 0.05$) was the single most dominant predictor of the adoption of VLAB.

B. Performance Improvement

All three groups individually showed significant improvement in performance ($\mathrm{p} < 0.05$) using the paired t-test; see Fig. 7.

An analysis of variance (ANOVA) was used to compare the mean improvement of the three groups, and the Bartlett test was used to verify that variances were indeed homogeneous. The difference in performance improvement between the groups was not significant, so this study suggests that simulations on desktops and tablets and work in physical labs had similar effects on student performance.

Though the average improvement in male students was slightly higher than in female students, Fig. 8, it was not statistically significant ($\mathrm{p} > 0.5$).

C. Student Feedback Analysis

Over a two-year period, feedback about VLAB OER was gathered from 50 563 students, as shown in Fig. 9. An overwhelming majority (72%) gave a high rating to the performance of the experiment (Excellent and Very good). Students felt they had control over the simulations, that the actual labs were well simulated, and that they gained a clear understanding of the experiment and the related topics.

VI. Conclusion

OER for virtual labs is still an emerging teaching–learning paradigm in engineering education. With over 1000 virtual experiments in use, VLAB is one of the largest and finest examples of multi-institutional OER effort exclusively focused on lab experiences. Deployed on a low-cost tablet, the approach has great potential to reduce the digital divide. The two-step diffusion approach of partners and Nodal Centers has resulted in significant

Fig. 9. Student feedback analysis.

faculty and student awareness of VLAB. The positive attitudes of thousands of faculty members have also lent great support to the VLAB OER movement. Although it is not clear if VLAB has reached its critical mass for adoption, indications are that this is very close.

This study was one of the first to provide empirical evidence of student learning outcomes adopting OER-like virtual labs and to compare performance of students using OER on both desktops and tablets. Student perceptions indicate VLAB attributes like Compatibility, Ease of Use, Relative Advantage, and Trialability as dominant factors for its adoption. The lab teams now have a framework for understanding what factors are important for adopting an OER like VLAB. Interestingly, attributes like the Department and Teacher Support did not seem to significantly influence potential-adopter student intentions. Student performances using virtual labs and physical labs were similar even though the average time for the physical lab was 105 min versus 50 min for the virtual labs. Overall feedback for virtual labs is overwhelmingly positive, with the majority of students giving a high rating to the performance of the experiments and indicating that they gained a clear conceptual understanding of the experiment and the related topics. Though a virtual lab cannot completely replace a physical lab, it offers an advantage when there is limited access to expensive equipment or limited time to perform experiments.

There are still challenges remaining. To sustain the use of VLAB OER, it is crucial that virtual labs be included in the lab timetable, and that the assessment of students' performance on these be integrated into their final grades. The VLAB development model also has to incorporate versioning, software issue-tracking, testing, copyrights, licensing, and release management. Sustaining VLAB beyond the initial government funding will require innovative business models. Finally, there is the international perspective—the current VLAB OER effort should become a global effort by collaborating with OER efforts like OCW, OLI, and others.

Acknowledgment

This project derives direction and ideas from the Chancellor of Amrita University, Sri Mata Amritanandamayi Devi. The authors would like to acknowledge the contributions of faculty at Amrita University and reviewers whose feedback and guidance were very valuable.

References

[1] H. Abelson and P. Long, "MIT's strategy for educational technology innovation, 1999–2003," *Proc. IEEE* vol. 96, no. 6, pp. 1012–1034, Jun. 2008.

[2] B. Gourley and A. Lane, "Re-invigorating openness at the Open University: The role of open educational resources," *Open Learning, J. Open, Distance E-Learning* vol. 24, no. 1, pp. 57–65, 2009.

[3] Z. C. Zacharia and C. P. Constantinou, "Comparing the influence of physical and virtual manipulatives in the context of the physics by inquiry curriculum: The case of undergraduate students' conceptual understanding of heat and temperature," *Amer. J. Phys.*, vol. 76, no. 4 & 5, pp. 425–430, 2008.

[4] G. Siemens, "Why we should share learning resources," 2003 [Online]. Available: http://www.elearnspace.org/Articles/why_we_should_share.htm

[5] J. C. Taylor, "The OER university: From logic model to action plan. Open planning meeting for the OER for assessment and credit for students project," 2011 [Online]. Available: http://wikieducator.org/OER_for_Assessment_and_Credit_for_Students/Meeting_Summary_-_23_Feb_2011

[6] W. Macintosh, R. McGreal, and J. Taylor, "Open Education Resources (OER) for assessment and credit for students project: Towards a logic model and plan for action. UNESCO Chair in Open Educational Resources," 2011 [Online]. Available: http://auspace.athabascau.ca:8080/dspace/handle/2149/3039

[7] U. D. Ehlers, "Open educational resources to open educational practices," *ELearning Papers*, vol. 23, pp. 1–8, 2011.

[8] A. J. Kezar and P. D. Eckel, "The effect of institutional culture on change strategies in higher education: Universal principles or culturally responsive concepts?," *J. Higher Educ.*, vol. 73, no. 4, pp. 435–460, 2002.

[9] M. Borrego, J. E. Froyd, and T. S. Hall, "Diffusion of engineering education innovations: A survey of awareness and adoption rates in U.S. engineering departments," *J. Eng. Educ.*, vol. 99, no. 3, pp. 185–207, 2010.

[10] E. M. Rogers, *Diffusion of Innovations*, 5th ed. New York, NY, USA: Free Press, 2003.

[11] Z. C. Zacharia, "Comparing and combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits," *J. Comput. Assist. Lear.*, vol. 23, no. 2, pp. 120–132, 2007.

[12] N. D. Finkelstein, W. K. Adams, C. J. Keller, P. B. Kohl, K. K. Perkins, N. S. Podolefsky, and S. Reid, "When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment," *Phys. Rev. Spec. Topics Phys. Educ. Res. 1*, pp. 010103:1–010103:8, 2005.

[13] J. Josephsen and A. K. Kristensen, "Simulation of laboratory assignments to support students' learning of introductory inorganic chemistry," *J. Chem. Educ. Res. Pract.*, vol. 7, no. 4, pp. 266–279, 2006.

[14] B. Dalgarno, A. G. Bishop, W. Adlong, and D. R. Bedgood, "Effectiveness of a virtual laboratory as a preparatory resource for distance education chemistry students," *J. Comput. Educ.*, vol. 53, no. 3, pp. 853–865, 2009.

[15] K. W. McElhaney, M. C. Linn, and J. Res, "Investigations of a complex, realistic task: Intentional, unsystematic, exhaustive experimenters," *J. Res. Sci. Teach*, vol. 48, no. 7, pp. 745–770, 2011.

[16] B. Kolloffel, T. de Jong, and T. H. S. Eysink, "Comparing the effects of representational tools in collaborative and individual inquiry learning," *Int. J. Comput. Supp. Collab. Learning*, vol. 6, no. 2, pp. 223–251, 2011.

[17] K. Achuthan, K. S. Sreelatha, S. Surendran, S. Diwakar, P. Nedungadi, S. Humphreys, S. Sreekala, Z. Pilla, R. Raman, A. Deepthi, R. Gangadharan, S. Appukuttan, J. Ranganatha, S. Sambhudevan, and S. Mahesh, "The VALUE @ Amrita Virtual Labs Project: Using web technology to provide virtual laboratory access to students," in *Proc. IEEE Global Humanitarian Technol. Conf.*, 2011, pp. 117–121.

[18] S. Diwakar, K. Achuthan, P. Nedungadi, and B. Nair, "Biotechnology Virtual Labs: Facilitating laboratory access anytime-anywhere for classroom education," in *Innovations in Biotechnology*, E. Agbo, Ed. Rijeka, Croatia: InTech., 2012, ch. 16, pp. 379–398.

[19] R. Raman, P. Nedungadi, K. Achuthan, and S. Diwakar, "Integrating collaboration and accessibility for deploying Virtual Labs using VLCAP," *Int. Trans. J. Eng. Manage. Appl. Sci. Technol.*, vol. 2, no. 5, pp. 547–560, 2011.

[20] R. B. Cooper and R. W. Zmud, "Information technology implementation research: A technological diffusion approach," *J. Manage. Sci.*, vol. 36, no. 2, pp. 123–139, 1990.

[21] A. R. Helsel, "Teachers' acceptance of innovation and innovation characteristics," *High Sch. J. Accountability Related Ideas*, vol. 56, no. 2, pp. 67–76, Nov. 1972.

[22] J. C. Nunnally, *Psychometric Theory*, 2nd ed. New York, NY, USA: McGraw-Hill, 1978.

Raghu Raman (M'08–SM'12) received the M.B.A. degree from the University of California, Berkeley, CA, USA, in 2003.

He is the Principal Investigator for the National Mission on Education through the ICT EdRP Project, Measuring Learning under the HP Catalyst Global Innovation, with Carnegie Mellon University, Pittsburgh, PA, USA, and for the Medical Simulation initiative under the Ministry of IT, India. He has over 14 years of product design and architecture experience from NEC Research Labs and IBM. Currently, he is guiding research projects in the areas of learning analytics, serious games, and virtual interactive learning environments.

Mr. Raman is Immediate Past Chair of the IEEE Education Society, India. He is a recipient of the President of India Gold Medal and of the IEEE Outstanding Chapter Award for 2013.

Krishnashree Achuthan received the Ph.D. degree in chemical engineering from Clarkson University, Potsdam, NY, USA, in 1998.

She heads the Center for Virtual and Accessible Laboratories Universalizing Education (VALUE @ Amrita), Amrita University, Kollam, India. VALUE @ Amrita has built over 30 virtual laboratories that are simulation-based, interactive, and/or remotely triggerable with over 300 experiments in the areas of physics, chemistry, biotechnology, computer science, and mechanical engineering. She is Principal Institute Coordinator for the National Mission on Education through the ICT at Amrita University. She has over 40 research papers and publications in peer-reviewed conferences and journals. She is also the author of 29 US patents. Her research interests include science and engineering undergraduate education, among others.

Prema Nedungadi (M'12) received the Master's degree in computer science from Jawaharlal Nehru University, New Delhi, India, in 1989.

She is the Joint Director of the Amrita Center of Research in Advanced Technologies for Education (CREATE) and faculty in School of Engineering, Amrita University, Kollam, India. She is Principal Investigator for the Online Science Labs and Adaptive Continuous and Comprehensive Evaluation research grants from the Government of India and Co-Principal Investigator for the Virtual Labs project under the National Mission in Education through the ICT. She has coauthored numerous scientific publications. Her research interests are in personalized e-learning solutions using computational intelligence methods, multimodal, and virtual reality systems for STEM learning and language learning.

Shyam Diwakar (M'01) received the Ph.D. degree in computational sciences from the University of Milan, Milan, Italy, in 2008.

Currently, he is an Assistant Professor with the School of Biotechnology, Amrita University, Kollam, India, where he is the head of the Computational Neuroscience Laboratory. Prior to that, he worked as a Postdoctoral Researcher with the Department of General Physiology, University of Pavia, Pavia, Italy. His research uses principles from electrical engineering and informatics to study the cerebellum and its functioning.

Dr. Diwakar is also a member of Indian Academy of Neurosciences, Organization of Computational Neuroscience Societies (OCNS), and the IACSIT.

Ranjan Bose (M'98–SM'11) received the B.Tech. degree in electrical engineering from the Indian Institute of Technology (IIT), Kanpur, India, in 1992, and the M.S. and Ph.D. degrees in electrical engineering from the University of Pennsylvania, Philadelphia, PA, USA, in 1993 and 1995, respectively.

Currently, he holds the Microsoft Chair Professorship and heads the Wireless Research Lab, IIT New Delhi, Delhi, India. He has held Guest Scientist positions with the Technical University of Darmstadt, Darmstadt, Germany; the University of Colorado at Boulder, Boulder, CO, USA; and UNIK, Oslo, Norway. He has published over 100 research papers in refereed journals and conferences and holds 10 patents. His research interests lie in the areas of ultrawideband (UWB) communications, broadband wireless access, and coding theory.