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Performance Impact of Simulation-Based Virtual Laboratory on Engineering Students: A Case Study of Australia Virtual System

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ABSTRACT Practitioners of virtual laboratory confront issues on how to fulfill individuals' needs, motivate them to participate and use the tools, and to enhance their performance using virtual tools. Therefore, this study aims at examining the effects of usability and learning objective factors in evaluating students' performance impact from using virtual laboratory. The study proposes a theoretical model based on usability factors of technology acceptance model (perceived ease of use and perceived usefulness) and laboratory learning objectives (instruments, creativity and innovation) to capture the entire patterns of students' perceptions and use outcomes from using the simulation-based virtual laboratory. The study collected survey data from 116 first year Electrical Engineering students from the University of Queensland in Australia, reflecting their personal experience in using virtual laboratory tools. Partial least square approach using structural equation modeling technique (PLS-SEM) was used for statistical analysis and model testing. The results confirm that the proposed model provides a comprehensive understanding of students' perceptions and the understudy factors were truly significant in reflecting their performance impact from using such laboratory tools. More specifically, instrumentation and perceived usefulness of virtual laboratory were found to be the most significant influencing factors that have impacts on students' performance. Also, the findings shed light on the mediation roles of laboratory learning objectives between usability factors and use outcomes. Overall, this study contributes to literature by demonstrating the beneficial use of laboratory learning objectives in creating realistic and credible simulation tool, that can expedite the learning process and foster students' learning outcomes.

INDEX TERMS Virtual laboratory, simulation laboratory, learning outcomes, performance impact, students' perceptions.

I. INTRODUCTION

Engineering education is associated with theoretical and practical knowledge, where engineering students are obligated to go beyond the conceptual understanding of theoretical knowledge and to acquire practical skills. The theoretical part can be gained during classroom learning activities while the practical knowledge involves acquired skills that can possibly be obtained through conducting experiment exercises in the physical laboratories (PLs). Students are be able to enhance their practical skills by handling real-world equipments in PLs experimentation [1]. However, they are not allowed to go beyond the scope of experiments, this is to avoid equipment damage and to minimize material and time-wasting [2]. On the other hand, online learning is not too easy on engineering courses due to the nature of the given field, which involve theoretical lectures along with experiment exercises in PLs. In this field, a simulation-based virtual laboratory (SVL) is an essential interactive tool that provides Engineering students with a virtual practical education [3].

Researchers have an extensive debates on the benefits and downsides of SVLs [4] and whether virtual laboratories (VLs) can stimulate similar excitement level as PLs do for Engineering students. In support for PLs, some researchers argued that students gain more information when dealing with real-world equipments [5], [6], others presented evidence that VLs and remote laboratories (RLs) are educational hindrances [7], [8]. In contrast, some research reported that students'

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conceptual understanding were identical or even had greater gains in VLs than in PLs, indicating that VLs are useful to supplement the learning process of PLs [9], [10]. Even some research presented support that VLs can adequately replace PLs [11]–[13].

In spite of the extensive research have been conducted on VLs, most of these studies have focused on the technical aspects of VLs such as instructional design, hardware/software architecture, and implementation of VLs [14]–[16], or comparison between VLs and PLs [17], [18] and between RLs and PLs [19]–[21]. On the other hand, researchers paid less attention to scientific research on measuring the educational performance of VLs from students' perspective and more precisely, two studies only were found in literature that have investigated the acceptance/adoption of VLs using theoretical models of technology acceptance [22], [23]. It seems that students' adoption and efficient use of VLs have been taken for granted in previous research. Neglecting the fact that the success of VLs depend not only on the technical aspects of VLs, but also on students' perceptions toward the learning tools. Therefore, a thorough evaluation is crucial for better understanding students' preferences of learning objectives and to empirically examine the driving power of SVL in Electrical Engineering education. This is to supplement the current field with quantitative insights and theoretical analysis on how well the instructional design of SVL influences students' perceptions of usefulness and easiness, meets their learning objectives, and having impact on the performance of engineering education.

Accordingly, this study proposes a theoretical model utilizing the usability determinants of technology acceptance model (TAM) [24] and employing some of the laboratory learning objectives of the accreditation board for engineering and technology (ABET) to measure the impact of SVL environment on students' performance in Electrical Engineering education at the University of Queensland in Australia. To the best of our knowledge, this is the first study that theoretically examine the laboratory learning objectives of ABET along with TAM in the context of VLs. Therefore, this study seeks to understand the causal relationships amongst the usability determinants of TAM, laboratory learning objectives of ABET, and the impact on students' performance from using of SVL tools. To achieve the study objective, the model examines individuals' needs and experience outcomes by taking into account individuals' psychological level (perceptions and needs) and their learning objectives, by which SVL fulfills users' needs and objectives, and how this self-fulfillment has an impact on users' performance. The following questions address the research purposes.

1) Does utilizing the laboratory learning objectives of ABET leads to improvement on performance impact?
2) What is the impact of using simulation-based virtual laboratory on students' performance?
3) What are the pedagogical benefits of using simulation-based virtual laboratory tools across Electrical Engineering?

II. LITERATURE REVIEW

Over the past years, the advance technology innovation supplemented PLs and visualized the possibility of instructional design of SVLs to support interactive learning for online environments.

A. LEARNING ENVIRONMENT OF SIMULATION-BASED VIRTUAL LABORATORY

The SVL used in this study [25] was developed with a web-based application and deployed to students as an optional learning tool to supplement the work of PL by emulating the experiences of real laboratory, facilitate performing the simulated experiments, and also to provide solutions for complex and complicated experiments without the need of using real equipments. The given study provided a good starting point for a joint participation and collaboration between practitioners and students, which assisted researchers to identify the design features of VLs based on the laboratory learning objectives of ABET, students' potential preferences, and their feedback during the development of such laboratory [26].

The platform of SVL was used by first year Engineering students, allowing them to conduct virtual version experiments at any time and place. The learning environment of SVL platform enabled students to connect active and passive components (e.g., resistors, capacitors, diodes, LEDs, and etc.) in circuits in a similar manner to real breadboard and to simulate these electronic circuits. It allowed students to carry out circuit simulation exercises based on actual mathematical formulas using the library of Ngspice circuit simulator, which is based on the software packages of Xspice, Spice3f5, and Cider1b1. Furthermore, user interface of the platform was designed to mimic the working experience in PLs and can be used to interface real-world equipments in PLs, thereby, it fits both SVL and RL. Once a user log in into the SVL, he/she can create a circuit project by dragging components into the breadboard simulator and the assembled virtual circuit will then be simulated using a remote server running SPICE3f5.

B. ABET LABORATORY LEARNING OBJECTIVES

International standard measures is crucial for evaluating the effectiveness of laboratories, which reflect the development of engineers competencies in laboratory settings. ABET formulated the most comprehensive criteria for evaluating the objectives of engineering laboratories, where fifty experienced engineering educators attended a workshop in San Diego, California on 2002 to determine the essential objectives of engineering-instructional laboratories regardless of instruction delivery. Thirteen comprehensive list of laboratories learning objectives were emerged from the workshop discussions. These objectives (instrumentation, models, creativity, experimental design, data analysis, design, and etc.) were summarized in [27], serving as principle guidelines for the assessments of PLs and can be used as criteria for evaluating the effectiveness of VLs.

C. VIRTUAL LABORATORIES AND ENGINEERING EDUCATION

Environment in laboratory enables students to engage in practical activities and to carry out experiment exercises related to the understudying topic. Accordingly, laboratory experiments sustain the learning process by augmenting the concepts of knowledge, helping students to enhance their experimental skills (e.g., experimental design, results analysis, and interpretation), improving problem-solving ability, and enhancing critical-thinking skills [28]. In general, PLs provide more control while virtual fields provide more realism. Yet, technology-enhanced laboratories that incorporated virtual experiments provide significant measures of control and limited realism [29].

Simulated laboratories are being used extensively in many universities, particularly in Engineering education within the universities premises. The indicator of extensive use was reflected by the regular stream publications in IEEE journals for various Engineering courses, including electronic circuits [30], communications technologies [31], electromagnetic [32], equipment calibration [33], semiconductor processing [34], and robotics [35]. The use of VLs as training activities for students and/or a pre-laboratory exercise before using PLs for experimentation have a significant learning improvement compared to using PLs without VLs, as well as improving information retention and boosting reflective learning [36]. Also, students using VLs have the opportunities to access the virtual resources as much they want (repetition and modification) and have enough time to complete laboratory activities, thereby, increasing deeper learning [37].

Reference [22] proposed a model (attitude, computer experience, preferences, simulation software experience, and cognitive style) to investigate the adoption of SVLs by Engineering students and also to evaluate the effectiveness of PLs and SVLs from students' perspectives based on their experience. Their findings revealed that both laboratories complement each other, where PLs provide students a valuable experience with hands-on exercises and SVLs support a comfortable effective learning environment. Another model was introduced recently integrating TAM with other factors (e.g., efficiency, playfulness, and satisfaction) to examine students' acceptance of VLs [23], these factors motivated students to engage in the learning process provided that the virtual tools and activities were designed properly, which in turn induced playfulness, satisfaction, and efficient experiences.

III. RESEARCH MODEL AND HYPOTHESES

One way to assess the performance of engineering-instructional laboratories is to view it from objectives perspective and therefore, this study seeks to identify and examine the factors that affect students' performance using SVL. More specifically, the authors utilize the usability factors [perceived ease of use (PEOU) and perceived usefulness (PU)] from the theory of TAM along with the measures of ABET laboratory learning objectives [instrumentation (INSTR), creativity and innovation (CI)] to draw a motivation sequence and to provide an explanation for the transformation of usability factors and learning objectives into IMPT. Figure 1 presents the proposed model with path link for each hypothesis.

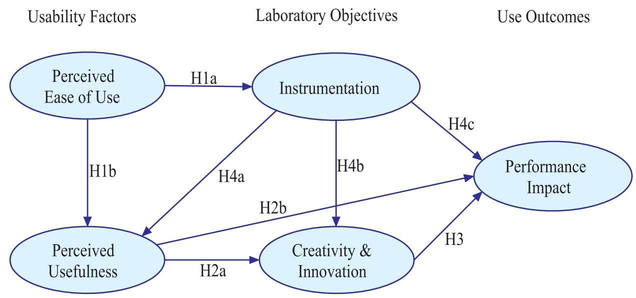

FIGURE 1. Research model.

A. USABILITY FACTORS: PERCEIVED EASE OF USE AND PERCEIVED USEFULNESS

PEOU is defined as "the degree to which a person believes that using a particular system would be free of effort" [38]. Therefore, it's believed that if users find SVL flexible and easy to use during performing practical activities, the greatest positive impact will be on instrumentation and usefulness of using SVL. Hence, we hypothesize the following:

H1a. Perceived ease of use would have a positive impact on instrumentation.

H1b. Perceived ease of use has a positive impact on perceived usefulness.

PU refers to "the degree to which a person believes that using a particular system would enhance his/her job performance" [38]. Therefore, if users perceive advantages of using the tools of SVL for hands-on exercises, this will stimulate their creativity and motivate them to enhance their performance. Consequently, we hypothesize the following:

H2a. Perceived usefulness would have a positive impact on creativity and innovation.

H2b. Perceived usefulness will have a significant positive effect on performance impact.

B. LABORATORY LEARNING OBJECTIVES: INSTRUMENTATION AND CREATIVITY-INNOVATION

The standalone usability factors are insufficient to assess the performance of using SVL tools for self-study and hands-on exercises. Therefore, INSTR and CI were utilized to be the standard references for laboratory learning objectives and to capture students' preferences, as well as mediating the positive effect of usability factors on IMPT.

Creativity refers to "the appropriate levels of independent thought, creativity, and capability in real-world problem solving" [27]. While innovation is the process that entails intellectual abilities and multiple activities to transform an idea into new valuable. In order to promote creativity and innovation, students have to be engaged in the experiment design development and should be given the autonomy to deal with problems of their experimental designs outcomes. Performing experiments in PLs are time bounded, which provide minimum space for deep thinking and creativity. In contrary, VLs provide an access to students anywhere anytime without time limitations, allowing an adequate time for creativity.

H3. Creativity and innovation will have a significant positive effect on performance impact.

INSTR refers to ''the application of appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities'' [27]. Students need to be trained on how to use the instruments accurately and effectively, and to be familiarized with its functions when measuring physical quantity. In SVLs, computer software represented by the instrument design replaces instruments, enabling student to observe the instrument structure and to examine its different features. While in modern PLs, devices are often controlled by automated instruments connected software, which shape the boundaries between PLs and VLs.

H4a. Instrumentation would have a positive impact on perceived usefulness.

H4b. Instrumentation would have a positive impact on creativity and innovation.

H4c. Instrumentation will have a significant positive effect on performance impact.

C. PERFORMANCE IMPACT

IMPT is defined in this field context as the degree to which using SVL has an effect on students acquisition of skills, effectiveness of learning, and tasks accomplishment. From literature on the individual measurement of IMPT, most researchers used three criteria of measures to assess IMPT such as the quantity and quality of outputs and the behavioral outcomes [39]; quantitative and qualitative measurement indicators (effectiveness, efficiency, and quality) [40]; while others referred these three measures to effectiveness, efficiency, and creativity [41]. However, IMPT in this study was measured based on students' perceptions, which is regarded as the set of an individual's realizations or the set of outcome results achieved during the interaction with SVL tool and therefore, students were asked to self-report their perceived impact on the overall performance of their learning using SVL tool. For example, when SVL tool meets students' preferences and task needs, they will have higher perceptions of usability and more advantage benefits, leading to better performance.

IV. RESEARCH METHODOLOGY

Partial least square (PLS) approach along with a variance-based structural equation modeling (SEM) technique was used to conduct the data analysis, hypotheses assessment, and model validation. This is because PLS puts less restriction on small sample size, assumption of multivariate normal distribution, and performing path analysis using ordinary least squares approach with multiple linear regressions, leading to a minimal residual variance on the dependent variables [42], [43]. Thereby, PLS-SEM method is an appropriate approach for this study.

A. QUESTIONNAIRE DEVELOPMENT

Consistent with prior research in the adoption/use of technology and relevant studies within the context of VL, this study adopted a quantitative research approach. The questionnaires were developed in the two stages of on-line surveys in order to collect data related to students' usability factors, laboratory learning objectives, and impact on students' performance from using SVL.

The participants indicated their agreement or disagreement with the questionnaires items using a 5-point Likert-type scale, ranging from ''Strongly disagree (1)'' to ''Strongly agree (5)''. Some of the items were adapted from prior studies with minor changes to reflect the SVL platform under investigation. For example, we adopted the items of usability (PEOU & PU) from prior research [24], [44] and were modified in relevant to SVL usage context. Also, the items measuring the laboratory learning objectives (INSTR & IC) and IMPT were adapted from prior study [45] based on the learning objectives recommended by ABET.

B. PARTICIPANTS AND DATA COLLECTION

This research is a longitudinal population-based cohort study of first year Electrical Engineering students undertaking DC circuit design course (ENGG1300) at the University of Queensland in Australia. This is to observe the changes over time and to gain a unique insight over the development of students' perceptions toward SVL. The breadboard simulator was deployed to students as an optional aid tool in this course. The study uses two stages of on-line surveys with a gap of three months between the stages. The first stage is the post deployment survey and was conducted at the start of the academic semester, this is to get students' feedback on the tool and their perceptions on usability factors (PEOU & PU). The second stage is the post-production implementation survey and was conducted at the last part of the same academic semester, and in this stage, we were mainly concerned about measuring students' perceptions toward using the breadboard simulator based on their actual use experience during the last three months.

Data was collected by means of a web-based surveys from students who registered in ENGG1300 and have used SVL. A total of 500 students who registered in the course were emailed asking them to use SVL voluntary in order to participate in the on-line survey. Based on the web-use log of the platform, 140 students were using SVL regularly and participated in the first stage survey. Those students were invited again to participate in the follow-up second stage survey. A total of 124 students participated in this survey, 116 survey responses were found valid and complete for further data analysis. Although some participants have dropped out from this study, the results can still be applied and generalized

TABLE 1. Descriptive statistics and factor loadings.

Construct/Item	Mean	Std	Loading	t-value
Perceived Ease of Use (PEOU)	4.22			
PEOU1. I find SVL wonderful to use	4.35	0.61	0.795	15.9
PEOU2. I find SVL easy to use	4.15	0.68	0.802	17.9
PEOU3. My overall experience using SVL is satisfying	4.55	0.59	0.865	23.2
PEOU4. I find SVL flexible to use	3.89	0.67	0.902	38.4
PEOU5. I find the software's interface of SVL is user-friendly	4.16	0.74	0.877	34.7
Perceived Usefulness (PU)	4.13			
PU1. SVL helps me to learn how to use the equipment	4.45	0.88	0.878	26.1
PU2. SVL helps me to understand theoretical concepts and models	4.19	0.83	0.900	34.5
PU3. SVL helps me to improve my critical thinking and analytical abilities	3.95	0.89	0.820	19.3
PU4. SVL helps me to develop the ability to design experiments	3.94	0.94	0.818	18.7
Instrumentation (INSTR)	4.11			
INSTR1. SVL makes me aware of what instruments should be used to measure a physical quality	4.18	0.89	0.925	54.0
INSTR2. SVL enables me to use instruments, components effectively, and accurately	4.13	0.91	0.943	70.1
INSTR3. SVL enables me to see the instrument structure and examine its different features	4.02	0.90	0.910	39.5
Creativity and Innovation (CI)	4.20			
CI1. SVL increases levels of independent thought and creativity	4.40	0.72	0.887	32.5
CI2. SVL helps solve real-world problems	4.24	0.72	0.841	27.4
CI3. SVL allows more time for creativity	4.03	0.77	0.845	30.1
CI4. SVL provides autonomy to deal with problems using innovative methods	4.12	0.76	0.854	31.9
Performance Impact (IMPT)	3.87			
IMPT1. Better understanding of lab equipments	4.26	0.75	0.895	34.1
IMPT2. SVL develops my ability to design experiments	4.12	0.81	0.856	25.4
IMPT3. SVL enables me to understand and perform the experiment easily	3.79	0.95	0.774	19.5
IMPT4. SVL develops critical and creative thinking skills	3.52	0.89	0.796	19.7
IMPT5. Using SVL, I have learned how to use lab equipments effectively	3.64	0.87	0.798	25.3
IMPT6. SVL stresses the importance of working safely with equipments	3.88	0.86	0.776	17.0

to a similar situation. Reference [46] recommended that the sample size of 116 for a population size of 500 with a confidence level of 95% and a margin of error of 5% at a sample proportion of 10% is considered adequate for the purpose of data analysis. The demographic characteristics of students in the class were relatively uniform (e.g., age, study field, study level) and most them were males. Therefore, the selected sample is an indicative of the whole class.

V. RESULTS

Data analysis and measurement/structural model estimation was carried out using SmartPLS 3 tool. For an accurate and adequate parameters' stability, PLS algorithm number of iterations and bootstrap subsamples were set to 300 cases and 5000 samples, respectively, with a 95% confidence intervals 2-tailed at a significance level of 5% as recommended by [47], [48].

PLS was used to assess the model fits parameters of the proposed structural model. Normed Fit Index (NFI $\geq$ 0.9) [49] and Standardized Root Mean Square Residual (SRMR $\leq$ 0.08) [50] are the most common model fits criteria in SmartPLS. The findings indicate a good model fit with both fitness indices, NFI = 0.905 and SRMR = 0.065 exceeded the threshold values of fit indices.

A. MEASUREMENT MODEL

The measurement model was evaluated based on the two criteria measures of reliability and validity. We first check the reliability of the model through determining Cronbach's alpha, composite reliability (CR) to assess the internal consistency measure of reliability, and outer loadings for individual items. Table 1 presents the descriptive statistics for indicator items and factor loadings for each item with its statistical t-value. All indictor items have outer loadings greater than the recommended cut-off value of 0.70, ranging from 0.774 to 0.943 [51].

Cronbach's alpha and CR for each construct are presented in Table 2. The findings of coefficient alphas exceeded the cut-off threshold value of 0.70 for all constructs, ranging from 0.875 to 0.917 [48]. Similarly, CR is analogous to coefficient alpha, reflecting the internal consistency of the indicator items measuring a particular construct. All constructs have CR values ranging from 0.916 to 0.948, satisfying the recommended cut-off threshold value of 0.70 for all constructs [48]. Therefore, the findings in the three criteria measures of reliability demonstrate a high reliability level.

For convergent validity, three criterions of assessments measures were adopted; (1) outer loadings of individual item, (2) CR, and (3) average variance extracted (AVE) of each construct [51]. The factor loadings of all items were greater than the recommended cut-off value of 0.70 and the values of CR in all constructs were above the threshold value of 0.70. Likewise, the values of AVE exceeded the recommended cut-off threshold value of 0.5 [51], ranging from 0.667 to 0.858. The obtained findings from the various fit indices of convergent validity were all satisfactory and demonstrated an adequate level of validity (see Table 1 and 2).

For discriminant validity, it has been evaluated through three criterions of measures; (1) inter-item cross loadings, (2) Fornell-Larcker criterion, and (3) Heterotrait-monotrait

TABLE 2. Assessment of reliability and convergent validity.

Constructs	Cronbach α	CR	AVE
PEOU	0.903	0.928	0.721
PU	0.875	0.916	0.731
INSTR	0.917	0.948	0.858
CI	0.879	0.917	0.734
IMPT	0.896	0.923	0.667

TABLE 3. Discriminant validity: inter-item cross loadings.

Items	CI	IMPT	INSTR	PEOU	PU
CI1	**0.887**	0.586	0.570	0.181	0.467
CI2	**0.841**	0.604	0.575	0.269	0.447
CI3	**0.845**	0.525	0.560	0.284	0.438
CI4	**0.854**	0.488	0.541	0.286	0.446
IMPT1	0.607	**0.895**	0.610	0.224	0.545
IMPT2	0.526	**0.856**	0.575	0.300	0.567
IMPT3	0.469	**0.774**	0.476	0.202	0.557
IMPT4	0.457	**0.796**	0.519	0.287	0.486
IMPT5	0.544	**0.798**	0.526	0.234	0.460
IMPT6	0.548	**0.776**	0.518	0.323	0.442
INSTR1	0.660	0.651	**0.925**	0.247	0.515
INSTR2	0.603	0.650	**0.943**	0.239	0.444
INSTR3	0.551	0.520	**0.910**	0.304	0.416
PEOU1	0.239	0.242	0.124	**0.795**	0.218
PEOU2	0.132	0.155	0.125	**0.802**	0.283
PEOU3	0.205	0.220	0.231	**0.865**	0.280
PEOU4	0.307	0.317	0.282	**0.902**	0.390
PEOU5	0.320	0.359	0.341	**0.877**	0.371
PU1	0.490	0.562	0.477	0.352	**0.878**
PU2	0.464	0.547	0.463	0.373	**0.900**
PU3	0.430	0.498	0.406	0.233	**0.820**
PU4	0.406	0.526	0.345	0.325	**0.818**

ratio (HTMT) criterion. As shown in Table 3, The findings illustrate that the indictor items measuring a particular construct are significant and extremely correlated and loaded higher on their particular construct.

Table 4 presents Fornell-Larcker correlation matrix for measuring discriminant validity, where the bold diagonal elements are the square roots of AVE, while the off-diagonal elements are the estimated correlations between the corresponding two constructs (corresponding rows and columns). Discriminant validity is confirmed satisfactory if the square root of AVE is consistently greater than the square root of the corresponding correlation [51]. The findings confirmed that all the square root of AVE are dominating over the corresponding squared correlations.

HTMT is a very reliable criteria for measuring discriminant validity, estimating the correlations between two constructs. As shown in Table 5, HTMT indicates a solid validity since all values are below the threshold value of 0.90 as recommended in [52]. Overall, the above assessments analysis entirely support reliability and validity (convergent and discriminant) of the model.

B. STRUCTURAL MODEL AND HYPOTHESES

Figure 2 presents the hypothesized structural model, showing the estimated regression path coefficients (β) with its

TABLE 4. Discriminant validity: inter-construct correlations (Fornell–Larcker).

Constructs	CI	IMPT	INSTR	PEOU	PU
CI	**0.857**				
IMPT	0.645	**0.817**			
INSTR	0.656	0.660	**0.926**		
PEOU	0.296	0.319	0.282	**0.849**	
PU	0.525	0.625	0.497	0.378	**0.855**

On-diagonal bold elements are the square roots of AVE.
Off-diagonal elements are the correlation estimates.

TABLE 5. Discriminant validity: inter-construct correlations (Heterotrait-monotrait ratio).

Constructs	CI	IMPT	INSTR	PEOU	PU
CI	–				
IMPT	0.721	–			
INSTR	0.726	0.720	–		
PEOU	0.319	0.338	0.287	–	
PU	0.596	0.702	0.548	0.403	–

significant level among the hypotheses and also the outer loadings of the indictor items with its significant level. As expected, PEOU has a significant effect on INSTR ($\beta = 0.282$, $t = 2.97$, $p < 0.01$) and on PU ($\beta = 0.258$, $t = 3.23$, $p < 0.001$). PU has a significant influence on CI ($\beta = 0.264$, $t = 3.20$, $p < 0.001$) and on IMPT ($\beta = 0.325$, $t = 3.80$, $p < 0.001$). CI has a significant influence on IMPT ($\beta = 0.259$, $t = 2.90$, $p < 0.01$). INSTR has a strong significant effect on PU ($\beta = 0.425$, $t = 4.31$, $p < 0.001$), on IC ($\beta = 0.524$, $t = 7.71$, $p < 0.001$), and on IMPT ($\beta = 0.328$, $t = 3.60$, $p < 0.001$).

PLS-SEM method also includes the assessment of estimated squared multiple correlation (R^2) value for each endogenous latent variable. The combined effects of the predictor variables explain variance for PU (i.e., 30.9%), INSTR (i.e., 8%), CI (i.e., 48.3%), and IMPT (i.e., 58.7%). In general, the endogenous variables illustrate high levels of variance R^2 and more specifically, the strong explained variance for IMPT is due to high inter-correlations among the predictor variables, revealing a high impact on students' performance and greatest advantage of using SVL.

Tables 6 shows the statistical significant relationships, direct and/or indirect effects between usability factors (PEOU & PU), laboratory learning objectives (INSTR & IC), and IMPT in the context of SVL. The results support the proposed hypotheses, where INSTR, CI, PU have direct effects on IMPT, while PEOU has an indirect effects on IMPT. For example, the total effects of INSTR on IMPT is the sum of direct and indirect effects through CI, is found to be 0.631. However, the total effects, i.e. direct effect of CI on IMPT is found to be 0.259.

VI. DISCUSSION AND IMPLICATIONS

The current study presents a holistic comprehension model that evaluates students' performance of using SVL, the model

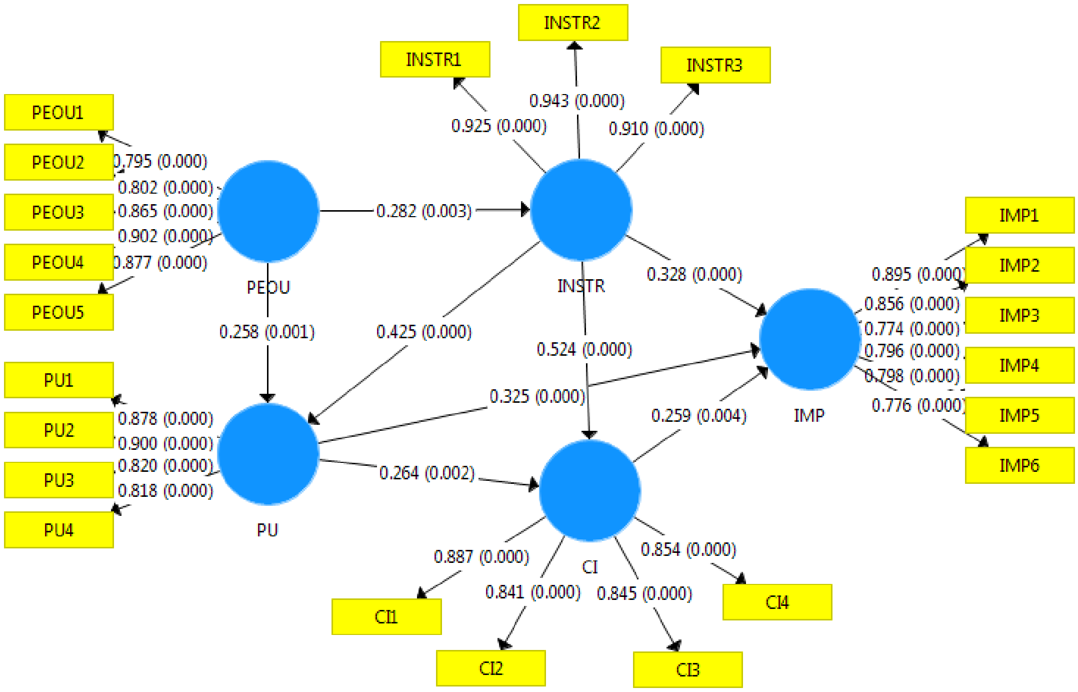

FIGURE 2. Results of PLS structural model.

TABLE 6. Summary of hypothesized results: direct and indirect effect.

H♯	Proposed relationship	Total indirect effect	Direct effect	Total effect	Supported
H1.a	PEOU (+) → INSTR	—	0.282^{**}	0.282^{***}	Yes
H1.b	PEOU (+) → PU	0.120^{*}	0.258^{**}	0.378^{***}	Yes
H2.a	PU (+) → CI	—	0.264^{**}	0.264^{***}	Yes
H2.b	PU (+) → IMPT	0.068^{*}	0.325^{***}	0.394^{***}	Yes
H3	CI (+) → IMPT	—	0.259^{**}	0.259^{***}	Yes
H4.a	INSTR (+) → PU	—	0.425^{***}	0.425^{***}	Yes
H4.b	INSTR (+) → CI	0.112^{***}	0.524^{***}	0.637^{***}	Yes
H4.c	INSTR (+) → IMPT	0.303^{***}	0.328^{***}	0.631^{***}	Yes

Notes: Path coefficient is significant at $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

was drawn from the usability factors of the leading theory of technology adoption, TAM (PEOU & PU), along with two objective factors, INSTR and CI adopted from the laboratory learning objectives of ABET. From students' perspective, this model investigates the influencing factors that affect the transformation of individual's behavior into an action and examines the causal relation between usability and objective factors, as well as providing an explanation for the transformation process of the intrinsic and extrinsic motivation factors (PEOU & PU) into use outcomes of SVL. Hence, this study provides a thoughtful justification for the factors that affect the performance of using SVL and can be used as a cornerstone for further research for capturing individuals' perceptions, preferences, and their use outcomes of SVL.

The findings feature support for the proposed model and hypotheses related to the path links between the model latent variables, mostly with a strong significant positive effects. Wherein, the explanatory power of the model explains variance ($R^2 = 58.7\%$) for students' performance, suggesting that TAM model along with the laboratory learning objectives of ABET are capable of explaining a high level of variation, particularly, for the impact on students' performance of using SVL.

For the usability factors, PEOU anticipates similar direct effects on INSTR ($\beta = 0.282$) and PU ($\beta = 0.258$), while having an indirect effects on the use outcomes of SVL through INSTR and PU. In other words, INSTR and PU mediate the relationships between PEOU and the use outcomes of SVL, these two indirect paths are the only paths that facilitate PEOU towards students' performance of using SVL. Whereas PU was more significant, explaining a stronger direct impact on students' performance ($\beta = 0.325$) rather than on CI ($\beta = 0.264$) of using SVL. Also, PU has an indirect effect on the use outcomes through CI, which mediates the relationship between PU and students' performance of using SVL. The findings illustrate that PEOU and PU are the drivers of INSTR and CI,. respectively, where students perceived no difficulty on measurements of quantities using instruments and they have developed an acceptable level of creativity to solve real-world problems.

As for the determinants of the laboratory learning objectives, INSTR is one of the most determinant that has a strong direct effects on PU ($\beta = 0.425$), CI ($\beta = 0.524$), and students' use outcomes ($\beta = 0.328$) of SVL, as well as having indirect effects on the use outcomes through PU and CI. Meanwhile, CI has a moderate direct effect on the use outcomes ($\beta = 0.259$). The findings showed that SVL enables students to use instruments and components effectively and to examine the different features of instrument structure. Although passing the laboratory examinations was most likely the priority for most students at using SVL, leading to an improvement on their performance. Accordingly, students were aware of the gained benefits from using SVL, as well as the positive impact on their performance. This implies that students were basically more concern on quantities measurements rather than creativity and innovation. This can be explained from three point of views, (1) students had insufficient time to use SVL platform, (2) students' intention of using the tool was only to gain the basic skills in order to pass the laboratory examinations, and therefore, (3) students were not able to fully develop a high levels of independent thought and innovative methods using SVL.

In consistent with previous research [24], [53], [54], the findings of this study can be clarified theoretically that the usability factors of TAM (PEOU & PU) are cognitive belief related to post-users' perceptions and mainly determined by their prior experiences in using SVL. While the laboratory learning objectives (INSTR & CI) play a central role in the model, mediating the cognitive belief into use outcomes. The above findings reflect the seriousness of students' usability of SVL, wherein their preferences and needs were probably confirmed during the interaction with the platform due to the advantages and efficiency of using SVL platform. The findings highlight the driving power of usability factors of TAM and the mediating role of the laboratory learning objectives on students' performance of using SVL.

A. THEORETICAL IMPLICATIONS

This study draws three theoretical implications for future research on the use outcomes of SVL. First, unlike most previous research on VLs that focused on the technical aspects of VLs, this study investigates the use outcomes of SVL from students' perspective by proposing a theoretical model and utilizing "IMPT" as the dependent latent variable.

Second, the empirical findings support all hypotheses and the holistic comprehension model illustrates a good explanatory power, revealing that the integration of TAM with the laboratory learning objectives of ABET provides a foundation model with theoretical and pedagogical basis for examining students' performance using SVL from students perspective. This research approach may provide new direction for further integration of other theoretical models in the context of VLs.

Third, the findings show that the usability factors of TAM model and the laboratory learning objectives of ABET have significant direct and/or indirect effects on students' performance using SVL, where PU and INSTR are the most influencing antecedents of IMPT that affect students' performance. While this study examined only two crucial learning objectives for laboratory, namely, INSTR and CI, in evaluating students' performance using SVL. This foundational contribution assists researchers to further explore more learning objectives and to combine relevant antecedents that affect the effectiveness of SVL tool, as well as shedding more light on how these objectives and potential antecedents can be manipulated to augment students' experience in using SVL.

B. PRACTICAL IMPLICATIONS

Students' preferences and needs are essential aspects that should be taking into account during the design and implementation stages of SVL tool, these aspects should be reflected on the design to address all needs and issues. The current study provides two practical implications for practitioners of SVL.

First, the instructional design of systematic VLs is not enough to guarantee its efficient use by students. In order to ensure the success of SVL tool, students' preferences and needs should be taken into consideration when designing such laboratories – a cornerstone that most engineering practitioners have overlooked.

Second, since the usability factors of TAM are cognitive belief formed mainly through users prior experiences in using SVL tool and the laboratory learning objectives of ABET mediate this cognitive belief into use outcomes. Therefore, practitioners of VLs should instruct post-users on how to use SVL effectively in order to augment their knowledge related to the usefulness of SVL tool, increase easiness perceptions toward SVL complexity, and to boost their use outcomes.

VII. LIMITATIONS AND FUTURE WORK

The findings of this study should be interpreted carefully in light of some limitations. First, the pedagogical effectiveness and performance of SVL was verified only for first year Electrical Engineering students and was limited to DC circuit design course at the University of Queensland in Australia. Therefore, the study was limited to students who engaged in using SVL, resulting in a small sample size, which may not represent all students from other universities or countries due to their diverse level of experience and culture differences. Accordingly, the findings may not deduce a consistent validity if applied to a dissimilar situation. Second, the author had no access to the participants' grades and therefore, this study limited the analysis of using SVL to students' perceptions of usability, advantages, and effectiveness in the assessment of IMPT based on their laboratory experiences.

Future research are suggested as follows. (1) Evaluating other laboratory learning objectives in order to draw a comprehensive view of the relation between these objectives and learning outcomes. Also, to integrate measures for evaluating the learning outcomes of using SVL, such measures may include satisfaction and academic performance. (2) To cover all aspect affecting students' performance using SVL, future researches are expected to examine the effects of moderator variables, moderating the relationships between latent variables and use outcomes. Also, to conduct a multi-group analysis, examining groups differences in terms of control variables. (3) Finally, conducting a comparison study between control group (students using VL only) and experimental group (students using SVL to supplement PL) to examine the effectiveness and performance of these laboratories in performing experiments for the same course.

VIII. CONCLUSION

Previous research have extensively focused on the technical aspects of VLs and few have investigated the adoption of SVL, while this study outruns these issues and provides in-depth insights into the use outcomes of SVL tool. The proposed model explores the relationships between usability factors (PEOU & PU), laboratory learning objectives of ABET (INSTR & CI), and use outcomes (IMPT), which explains the needs of individual and use outcomes by considering the psychological level of users and their learning objectives, by which SVL fulfills each individual's needs and objectives, and how this self-fulfillment affects the use outcomes. The pedagogical evaluation of SVL from students' perspective shows that SVL can be a useful tool for Electrical Engineering education. Whereas both factors, INSTR and PU anticipate larger impact on students' performance than CI, revealing that both factors are the most important predictors of IMPT. In addition, this study revealed that the laboratory learning objectives mediate the established relation between usability factors and use outcomes. Overall, the findings of this study imply that using SVL experimentation is an appropriate learning exercise to bolster the learning process and to supplement the traditional laboratories. Such SVL tool enables students to perform pre-laboratory exercise activities, enhances their practical learning experience, and boosts their learning performance.

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