INTERNATIONAL MULTIDISCIPLINARY JOURNAL OF RESEARCH FOR INNOVATION, SUSTAINABILITY AND EXCELLENCE (IMJRISE)
Online ISSN: 3028-032X | Print ISSN: 3028-0370
PUBLISHED BY: RISEJOURNALS.ORG
Volume 2, Issue no. 1

Examining Undergraduate Student Acceptance of Virtual Laboratories in Physics Classes: An Extended TAM Model

DOI: 10.5281/zenodo.14587141

Rim Gouia Zarrad & Rim Gharbi
South Mediterranean University (MSB-MedTech-LCI), Les Berges du Lac 2, Tunis, Tunisia
https://orcid.org/0000-0002-0783-6076 | rim.gouia@medtech.tn

Abstract

Following the COVID-19 pandemic, virtual laboratories have gained popularity in higher education. It is essential to explore the factors influencing students' acceptance of these virtual labs, particularly in the field of physics where research remains limited. This study proposes a framework based on the Technology Acceptance Model (TAM) to examine the factors of behavioral intention among undergraduate engineering students regarding virtual lab usage. The TAM model was extended by integrating prior experience, perceived enjoyment, facilitating conditions, and information quality. A partial least square structural equation modeling was employed to analyze the survey responses from 80 undergraduate engineering students at South Mediterranean University. Results indicate that students' behavioral intention is directly influenced by perceived usefulness and indirectly influenced by information quality and perceived enjoyment. The findings of this study provide valuable insights for educators and instructional designers to improve the design and the effectiveness of virtual labs in physics classes.

Keywords: virtual laboratory, technology acceptance model (TAM), e-learning, higher education, smart PLS

Introduction

In recent years, the field of education has undergone a transformation marked by the integration of technology into traditional learning environments (DiSessa, 2000). In fact, technology has not only redefined education but has also revolutionized the landscape of scientific laboratories in the form of virtual/simulated laboratories or remote laboratories (Duan et al., 2005; Finkelstein et al., 2005; Potkonjak et al., 2016; Steinberg, 2000). Moreover, the recent COVID-19 pandemic has further accelerated the adoption of these virtual environments (Gamage et al., 2020; García-Vela et al., 2020; Joshi et al., 2021; Radhamani et al., 2021).

Laboratory practice is a fundamental pillar of physics education, offering students opportunities to understand the theoretical concepts taught in the classroom. Often referred to as "a playground for experimentation" (Mercer et al., 1990), it serves as a space for hands-on exploration of equipment in various scientific domains. As Clough mentioned in 2002, "laboratory experiences make science come alive".

Within the realm of virtual environments, we notice the emergence of two distinct techniques that need to be differentiated. The first involves the replication of experiments through the development of fully computer-based simulations, resulting in what is termed a virtual laboratory (Alnagrat et al., 2021; Budai & Kuczmann, 2018; Gamo, 2018). The second technique, known as a remote laboratory, allows for the interaction with real equipment at a distance, distinguishing itself from physical labs by the spatial separation between the experiment and the experimenter (Elawady & Tolba, 2009). For practical reasons, we chose to concentrate our research on virtual laboratories due to their efficiency and scalability. In fact, they eliminate the need for complex hardware to control equipment, reduce maintenance, and enable multiple students to access the laboratory simultaneously (Potkonjak et al., 2016).

Towards the end of the 20th century, virtual laboratories emerged, introducing an entirely novel approach to the practice of theoretical concepts. They engage students with virtual experiments through simulations and animations (Diwakar et al., 2015; Nair et al., 2012; Radhamani et al., 2014; Tüysüz, 2010). In Alnagrat et al., (2023), authors define virtual laboratories as "an effective replicate of the characteristics and functionalities of traditional physical laboratories". Researchers have engaged in extensive debates surrounding the role of virtual laboratories. Many studies report that virtual laboratories can serve as replacements for physical laboratories (Brinson, 2015; Corter et al., 2011; Kolloffel & de Jong, 2013; Lang, 2012; De la Torre et al., 2013; Sheorey, 2014; Triona & Klahr, 2003; Zacharia, 2003; Zacharia & Olympiou, 2011), while others view them as valuable training platforms that complement the learning objectives of physical laboratories (Byukusenge et al., 2023; Chu & Fang, 2015; De Vries & May, 2019; Ekmekci & Gulacar, 2015; Gamo, 2018; Magin & Kanapathipillai, 2000; Mishra et al., 2020; Potkonjak et al., 2016; Radhamani et al., 2021; Raineri, 2001; Sell & Seiler, 2012; Ng, 2022).

The adoption of virtual laboratories has gained significant popularity (Dhawan, 2020), due to the advantages they offer, as highlighted in various studies (Fiscarelli et al., 2013; Groenewald et al., 2024; Rotimi et al., 2012; Rutten et al., 2012; Smetana & Bell, 2012; Tatli & Ayas, 2011; Trundle & Bell, 2010; Zabunov, 2013; Zhou et al., 2024).

These virtual laboratories provide a secure environment for students to explore risky scenarios and enhance safety when handling hazardous materials. Moreover, they offer flexibility by allowing experiments at any time, ultimately enhancing the educational experience. Institutions facing budget constraints and limited access to advanced facilities find virtual laboratories to be a cost-effective alternative for practical activities (Flowers, 2011; Wang, 2018). These labs also improve the quality of learning, particularly in instrumental analysis, by reducing both time and expenses compared to physical laboratories (Bortnik et al., 2017; Estriegana et al., 2019; Zurweni et al., 2017). They enable students to apply theoretical knowledge in an enjoyable learning environment, and keep users updated with the latest technologies. Students can repeatedly practice experiments in virtual labs not only to improve the learning quality but also to enhance their metacognitive skills (Gunawan et al., 2018; Mishra et al., 2020; Yusuf & Widyaningsih, 2020).

As universities are converting more and more to virtual laboratories, it is essential to consider the students' perceptions towards them in assessing the effectiveness of innovative educational technologies (Freiberg, 1999). Positive perceptions of the learning experience "influence student engagement and motivation, while negative perceptions can lead to disengagement and hinder academic success" (Jones & Carter, 2019). As mentioned by Elawady and Tolba (2009) "the effectiveness of laboratories may be affected by how much students believe in them''. Little is known about the acceptance of virtual labs in higher education and more specifically in the STEM field, in the post-pandemic context. In addition, it is important to note that prior to COVID-19, virtual laboratories were not widely utilized in Tunisia, and their potential remains unexamined. This study aims therefore to gain an insight into undergraduate students' perception towards virtual laboratories in Tunisia, by examining the factors influencing their acceptance and usage of these labs; and thereby contributing to our understanding of this innovative educational tool in the context of a developing country. To achieve this goal, an extended Technology Acceptance Model (TAM) is employed as a theoretical framework where we integrate prior experience, perceived enjoyment, facilitating conditions, and information quality as external variables to investigate the factors of students' acceptance.

This paper is organized as follows: it begins with a literature review on students' acceptance of virtual laboratories, followed by a description of the research methodology, participants, and instruments. The findings are then presented, followed by a discussion. Finally, the paper concludes with an acknowledgment of its limitations.

Literature Review

According to Davis (Davis, 1986; Davis, 1989; Davis et al., 1989), the Technology Acceptance Model (TAM) is a well-known framework widely used to investigate users' acceptance of new technologies. Several researchers have validated TAM within diverse contexts including information system context (Park & del Pobil, 2013), use of computers in the workplace (Davis et al., 1992), e-banking, health care (Holden & Karsh, 2010), web user behavior (Lederer et al., 2000) and smartphone credit cards (Ooi & Tan., 2016). As suggested by Venkatesh et al. (2003), "TAM is robust across time, settings, populations, and technologies". In the context of education, several authors have used TAM to examine factors of student acceptance of e-learning (Khan et al., 2023; Salloum et al., 2019; Tarhini, 2017), blended learning (Al-Busaidi, 2013; Jnr et al., 2020), online learning (Liu et al., 2010), Moodle (Rivers, 2021), Google apps (Rejón-Guardia et al., 2020), institutional mobile application (Petersen, 2020), digital platforms (Singh, 2023), chatbots (Almahri et al., 2020), AI driven assessment (Cruz-Benito et al., 2019) and digital library (Rafique et al., 2020).

Although there are numerous studies that widely use TAM framework in education research (Granić & Marangunić, 2019), only a limited body of research has used TAM to examine the factors of students' acceptance of virtual laboratories in higher education. In Estriegana et al. (2019), the authors have proposed an extension of TAM to explore students' behavior regarding potential acceptance or rejection of virtual laboratories in the course fundamentals of computer technology. Their study included new factors in the TAM namely perceived efficiency, playfulness, and satisfaction. Another work (Gamo, 2018) has used the TAM model to prove that a virtual laboratory in optics (named OPTILAB) is a good tool to enhance learning and to assess students' satisfaction with OPTILAB in Physics course. To the research model, the following external variables were added: demographic variables, system accessibility, self-efficacy, and subjective norm. In the research done by Radhamani et al. (2021), authors have examined the acceptance of virtual laboratories which were implemented as a curriculum material pre- and post-COVID-19 in a laboratory course. In Christabel and Prawira (2023), the technology acceptance model (TAM) was used to analyze users' experience with digital learning and broadcasting virtual laboratory in the post-pandemic era. Another recent study (Tobarra, 2020) has examined students' acceptance of a new container-based virtual laboratory in cybersecurity. They have used an improved TAM model with several indicators: perceived usefulness, estimated effort, social influence, attitude, ease of access, and intention of use. Similarly, in the same subject, Robles-Gomez et al. (2021), have used two structural equation models, the psychological TAM, to examine students' acceptance of virtual remote laboratories. The proposed model is based on the external variables: perceived usefulness, estimated effort, social influence, attitude, ease of access. In (Robles-Gómez et al., 2021), students were asked their opinion about the virtual laboratory and their general experience in terms of external variables: performance expectancy, effort expectancy, user attitude, social influence and facilitating conditions based on the

TAM model. Moreover, the results obtained by Altalbe (2019), explore the relationships between usability factors (perceived ease of use and perceived usefulness) from the theory of TAM, the ABET laboratory learning objectives (instrumentation and creativity & innovation) and use outcomes (performance impact) in DC circuit design course.

To the best of our knowledge, no prior studies have extended the TAM model by incorporating variables such as prior experience, perceived enjoyment, facilitating conditions, and information quality. In addition, there is a lack of research on virtual laboratories in Tunisia, despite their growing relevance in contexts with resource constraints and limited access to advanced facilities. This highlights the need to explore students' acceptance of virtual laboratories in Tunisia and, by extension, in developing countries.

Methodology

In this study, a theoretical model is developed using the TAM as a framework to examine the factors that influence undergraduate students' acceptance of virtual labs in physics classes. The Technology Acceptance Model (TAM) is based on the Theory of Reasoned Action (TRA) (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975) which distinguishes between belief, attitude, and intention. According to TAM (Davis, 1989; Davis et al., 1989), behavioral intention to use a technology is determined by attitude toward usage which is influenced by beliefs. Two key beliefs determine attitude: perceived usefulness and perceived ease of use. In addition, the construct perceived ease of use has a direct effect on perceived usefulness because "the easier a technology is to use the more useful it can be" (Venkatesh et al., 2003). However, perceived usefulness has no direct effect on perceived ease of use.

While the Technology Acceptance Model (TAM) is a valuable tool for examining acceptance, its limitation lies in the lack of determining the factors that impact ease of use and usefulness. Therefore, based on their research objective and context, many scholars have expanded the TAM by adding external variables to provide a more complete model. Building upon previous research, we have extended TAM model by adding the following external variables: prior experience, perceived enjoyment, facilitating conditions, and information quality. These factors may directly influence perceived usefulness and perceived ease of use, while also indirectly influence attitude toward usage and behavioral intention. The selected constructs are defined in Table 1 and shown in Figure 1, which represents our research model. Table 2 provides an overview of the hypotheses.

Table 1. Definitions of variables in TAM

Construct	Definition of construct	Ref
Perceived Ease of Use	Degree to which a person believes that using a particular system would be free of effort	Davis 1989 p 320
Perceived Usefulness	Degree to which a person believes that using a particular system would enhance his or her performance	Davis 1989 p 320
Attitude toward Usage	An individual's positive or negative feelings about performing the target behavior	Fishbein & Ajzen, 1975
Behavioral Intention	Measure of the likelihood a person would employ the application	Ajzen & Fishbein, 1980
Prior Experience	Whether learners have experiences in a particular system	Liao & Lu, 2008
Perceived Enjoyment	Degree to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance resulting from system use	Davis et al., 1992
Facilitating Conditions	Objective factors in the environment that observers agree make an act easy to accomplish	Venkatesh et al., 2003
Information Quality	Degree to which the user receives complete, precise and well-timed information over the service interface	Salloum et al., 2019

The external variables and their related hypotheses are discussed as follows:

Prior experience: Several studies insert prior experience as an external factor in TAM and link it to behavioral Intention (Ajzen & Fishbein, 1980; Bagozzi, 1981; Bentler & Speckart, 1979; Fishbein & Ajzen, 1975; Triandis, 1977). According to Eagley and Chaiken (1993), knowledge gained from prior behavior will determine behavioral intention because experience makes knowledge more accessible in memory (Fazio & Zanna, 1978; Reagan & Fazio, 1977). It is also one of the most commonly used external variables for e-learning (Abdullah & Ward, 2016). We hypothesized that Prior Experience would have a significant positive effect on perceived ease of use (H1) and on perceived usefulness (H5).

Perceived enjoyment: Davis et al. (1992) defines perceived enjoyment as "the degree to which an activity using a technology is perceived as enjoyable or pleasurable to itself". Moon & Kim (2001) state that "when individuals are in the playfulness state, they will find the interaction intrinsically interesting: they are involved in the activity for pleasure and enjoyment rather than for extrinsic rewards". Several studies therefore insert perceived enjoyment as a factor in TAM and link it with perceived ease of use in online or virtual learning environments. Moreover, Estriegana et al. (2019) find that the playfulness of virtual laboratories positively influences perceived usefulness and perceived ease of use. Webster et al. (1990) find that playfulness or enjoyment highly correlates with positive user attitudes. We hypothesized that perceived enjoyment would have a significant positive effect on perceived ease of use (H2) and perceived usefulness (H6).

Facilitating conditions: Several studies have added facilitating conditions in TAM when using virtual laboratories. For example, Robles-Gómez et al. (2021) find that facilitating the conditions of virtual laboratory affects the students' attitude. In other words, "whether a student thinks that access to the platform is more or less complex, his or her attitude towards it may be more or less negative". In addition, Tobarra et al. (2020) conclude that the ease of access strongly affects the perceived usefulness and the students' attitude when using virtual laboratories in cybersecurity. Other authors have investigated facilitating conditions in understanding students' behavioral intention to use an e-learning system (Huang et al., 2022; Sukendro et al., 2020). We hypothesized that facilitating conditions would have a significant positive effect on perceived ease of use (H3) and perceived usefulness (H7).

Information quality: In recent studies, Information Quality is often considered as a factor for behavioral intention (Urbach & Müller, 2012), especially in the context of e-learning (Li et al., 2012; Virani et al., 2023; Zhang et al., 2022). We hypothesized that information quality would have a significant positive effect on perceived ease of use (H4) and perceived usefulness (H8).

Table 2. Hypotheses

	Hypothesis
H1	Prior Experience will have a significant positive effect on Perceived Ease of Use
H2	Perceived Enjoyment will have a significant positive effect on Perceived Ease of Use
H3	Facilitating conditions will have a significant positive effect on Perceived Ease of Use
H4	Information Quality will have a significant positive effect on Perceived Ease of Use
H5	Prior Experience will have a significant positive effect on Perceived Usefulness
H6	Perceived Enjoyment will have a significant positive effect on Perceived Usefulness
H7	Facilitating conditions will have a significant positive effect on Perceived Usefulness
H8	Information Quality will have a significant positive effect on Perceived Usefulness
H9	Perceived Ease of Use will have a significant positive effect on Perceived Usefulness
H10	Perceived Usefulness will have a significant positive effect on the Attitude toward usage
H11	Perceived Ease of Use will have a significant positive effect on Attitude toward usage
H12	Attitude toward usage will have a significant positive effect on Behavioral Intention

Hence, the study is guided by the preceding hypotheses, showing the relationship between the eight constructs, and illustrated in the following model:

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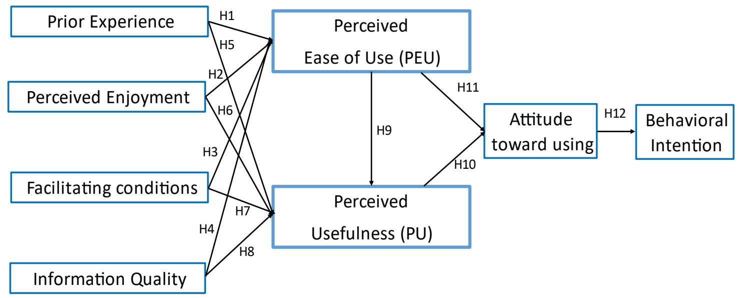

Figure 1. TAM research model

Participants and data collection

The analysis was conducted using data obtained from 80 undergraduate engineering students comprising 34 females and 46 males taking physics courses. Participants were comprised of two groups: first year and second year students. The first-year engineering students took the Classical Mechanics course which is fundamental for understanding motion, moment of forces, and energy conservation in mechanical systems. The second-year engineering students took the Optics and Waves course, which explores the study of waves, laws of reflection and refraction, and phenomena of interference and diffraction of light.

These physics courses included a biweekly laboratory component to apply theoretical concepts learned in lectures. Midway through the semester, the professor decided to conduct one laboratory session virtually, where students independently created accounts on a free online platform and completed the exercise in class. The professor was present throughout the session to assist with any technical issues, such as account creation or internet connectivity problems, ensuring that all students could complete the exercise without disruptions. At the end of the session, students completed a web-based survey on-site to evaluate their experience and acceptance of the virtual laboratory. Participation in the study was entirely voluntary, with no incentives or rewards offered. The survey used a 5-point Likert scale, with responses ranging from 1 (“strongly disagree”) to 5 (“strongly agree”). All 80 students in the final sample responded to the survey 46 males and 34 females, predominantly aged 18 or 19. On average, students took approximately 12 minutes to complete it.

Based on previous research (Radhamani et al., 2021), we chose the free platform Amrita (https://vlab.amrita.edu/index.php) for the first-year group to investigate elastic and inelastic collisions as well as to obtain values of kinetic energy, velocity, and momentum (refer to Figure 2).

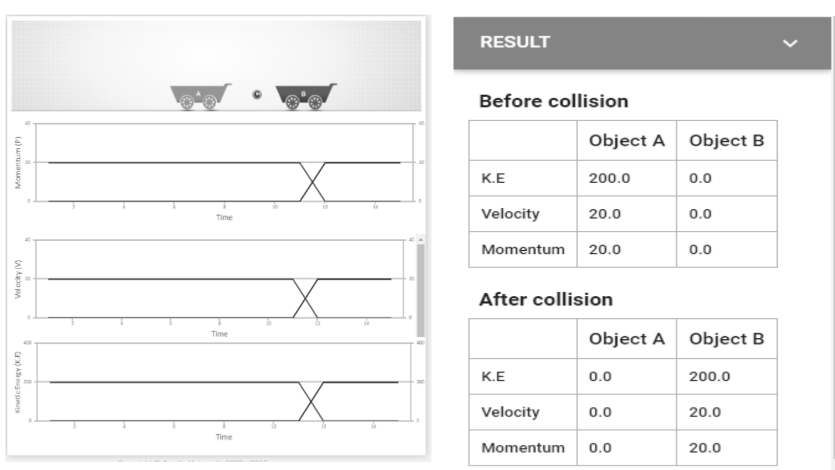

Figure 2. Screen shoot of the result after collision

Based on previous research (Abdjul & Ntobuo, 2018; Zulkifli et al., 2022), we chose the free platform PHET (PHET https://phet.colorado.edu/) for the second-year group to explore standing waves, discuss various resonant modes of vibrations, and calculate the fundamental resonant frequency (refer to Figure 3).

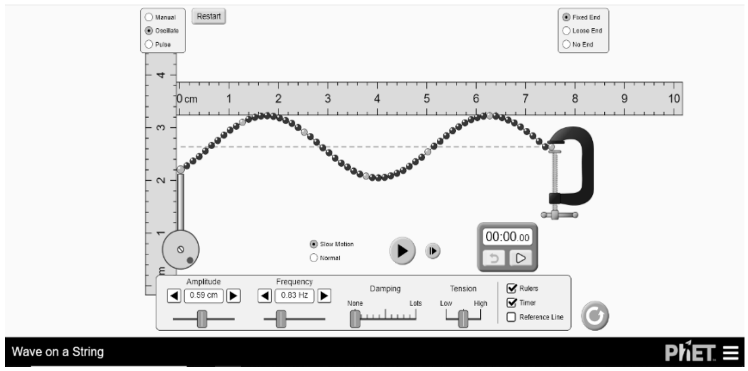

Figure 3. Screen shoot of the virtual experiment

Findings

The Partial Least Squares System Equation Modeling (PLS-SEM) was used to analyze the System Equation Modeling (SEM) based on the optimization technique of partial least squares (Hoyle, 1995). As mentioned by Hair et al. (2017) "PLS-SEM path modeling can indeed be a 'silver bullet' for estimating causal models in many theoretical model and empirical data situations''. The data analysis is a two-stage process that involves separate assessments of the measurement model and the structural model. First, we measure the reliability and validity of all constructs, then we test the relationship between the constructs. As mentioned by Fornell and Larcker (1981) "Before testing for a significant relationship in the structural model, one must demonstrate that the measurement model has a satisfactory level of validity and reliability". Moreover, all the data analysis was conducted using SmartPLS 4.0 (Ringle and al., 2022).

1.Assessment of the measurement model: To examine the measures' reliability and validity, the methods used in this study were based on "the rules of thumb for model evaluation" (Hair et al., 2010; Hair et al., 2011; Hair et al., 2021). In other words, the assessment of the measurement model implies the evaluation of the indicator reliability, internal consistency reliability, convergent validity and discriminant validity.

Indicator reliability: As shown in Table 3, all the factor loadings are above 0.7, which implies acceptable indicator reliability (Carmines & Zeller, 1979; Hair and al. 2010). For the construct prior experience, the factor loading is equal to 1. Hence, we have perfect reliability because the construct is the same as the indicator.

Internal consistency reliability: The results of the composite reliability (CR) of each construct are shown in Table 4 indicating a high level of internal consistency reliability among constructs. In addition, we can calculate Cronbach's alpha to measure the degrees of internal consistency of the results (Cronbach, 1970; Nunnally & Bernstein, 1994), as mentioned by Tompson et al. (1995) "CR is analogous to Cronbach's alpha, and the 0.7 standards suggested by Nunnally" (Nunnally, 1978). Table 4 shows that the measurement scales were highly reliable, with Cronbach's alpha values for the eight constructs range from .75 to .90.

Convergent validity: As shown in Table 4, all values for the average variance extracted (AVE) were above 0.50 which is the minimum acceptable value suggested by Fornell & Larcker's (1981), indicating good convergent validity.

Discriminant validity: Fornell-Larcker's criterion verifying that the square root of the AVE for each construct should be higher than its correlation coefficients across constructs (Fornell & Larcker, 1981). The diagonal element in Table 5 represents the AVE for the constructs, while the off-diagonal elements represent the correlation coefficients across constructs. It indicates acceptable discriminant validity of the measurements. As a result, it is confirmed that the reliability and validity of the model were acceptable.

Table 3. Factor Loadings and Cross loadings.

	BI	ATT	FC	IQ	P1	PENJ	PEU	PU
BI1	1.000	0.909	0.602	0.780	0.228	0.917	0.553	0.779
A1	0.836	0.924	0.699	0.853	0.292	0.823	0.654	0.826
A2	0.866	0.943	0.606	0.824	0.214	0.912	0.581	0.786
A3	0.828	0.918	0.554	0.710	0.277	0.833	0.503	0.664
FC1	0.412	0.524	0.833	0.548	0.093	0.390	0.671	0.484
FC2	0.514	0.521	0.853	0.558	0.155	0.506	0.647	0.428
FC3	0.619	0.673	0.910	0.720	0.226	0.641	0.771	0.730
IQ1	0.705	0.760	0.656	0.952	0.115	0.695	0.633	0.752
IQ2	0.781	0.878	0.700	0.954	0.257	0.831	0.649	0.767
P1	0.228	0.281	0.189	0.196	1.000	0.191	0.293	0.309
PENJ1	0.899	0.921	0.611	0.787	0.205	0.978	0.572	0.740
PENJ2	0.893	0.882	0.566	0.781	0.169	0.977	0.544	0.727
PEU1	0.483	0.594	0.753	0.619	0.263	0.582	0.844	0.618
PEU2	0.509	0.510	0.612	0.517	0.358	0.450	0.864	0.530
PEU3	0.407	0.456	0.640	0.543	0.173	0.380	0.878	0.534
PEU4	0.540	0.627	0.821	0.675	0.243	0.572	0.941	0.642
PU1	0.719	0.737	0.571	0.687	0.355	0.655	0.582	0.916
PU2	0.619	0.659	0.575	0.614	0.271	0.619	0.569	0.832
PU3	0.750	0.803	0.606	0.827	0.216	0.739	0.632	0.940

Note: ATT = Attitude toward usage, P = Prior Experience, PENJ = Perceived Enjoyment, FC= Facilitating conditions, IQ = Information Quality, PU = Perceived Usefulness, PEU = Perceived Ease of Use, BI = Behavioral Intention

Table 4. Cronbach's alpha coefficients, Rho_A, composite reliability and average variance extracted.

	Cronbach's alpha	Rho_A	Composite reliability	Average variance extracted
ATT	0.920	0.923	0.949	0.862
FC	0.834	0.861	0.900	0.750
IQ	0.899	0.899	0.952	0.908

PENJ	0.954	0.955	0.978	0.956
PEU	0.905	0.915	0.934	0.779
PU	0.877	0.889	0.925	0.805

Table 5. Discriminant validity matrix (Fornell-Larcker criterion)

	BI	ATT	FC	IQ	P1	PENJ	PEU	PU
BI	1.000							
ATT	0.909	0.928						
FC	0.602	0.670	0.866					
IQ	0.780	0.860	0.712	0.953				
P1	0.228	0.281	0.189	0.196	1.000			
PENJ	0.917	0.922	0.602	0.802	0.191	0.978		
PEU	0.553	0.627	0.810	0.673	0.293	0.571	0.882	
PU	0.779	0.820	0.650	0.797	0.309	0.750	0.663	0.897

2.Assessment of the structural model: To examine the structural model, the methods used in this study were based on “the rules of thumb for model evaluation” (Hair et al., 2010; Hair et al., 2011). The structural model was tested by examining the coefficient of determination R^2 as well as the path coefficient and its statistical significance in relation to each construct.

The coefficient of determination (R^2) is a commonly used parameter (Tompson et al., 1995). According to Hair et al. (2011), R^2 values of 0.75, 0.50, or 0.25 can, as “a rule of thumb”, be described respectively as substantial, moderate, or weak. The results of PLS-SEM are summarized in Table 7. They show, for example, that R^2 is 0.692 for ease of use. This indicates that P, PENJ, FC and IQ explain 69.2% of the variance in ease of use.

Following the recommendations of Hair et al. (2011), the bootstrapping procedure with 5000 resamples was employed to find the significance level of the hypotheses. The smaller the p-value is, the stronger the evidence against the null hypothesis, and the more statistically significant the result is (Pallant 2020; Tompson et al. 1995). Table 6 and Figure 4 present the path coefficients and the 12 hypotheses results. As displayed in Table 6, the hypotheses H3, H6, H8, H10, and H12 were supported while the remaining hypotheses H1, H2, H4, H5, H7, H9, H11 were not supported.

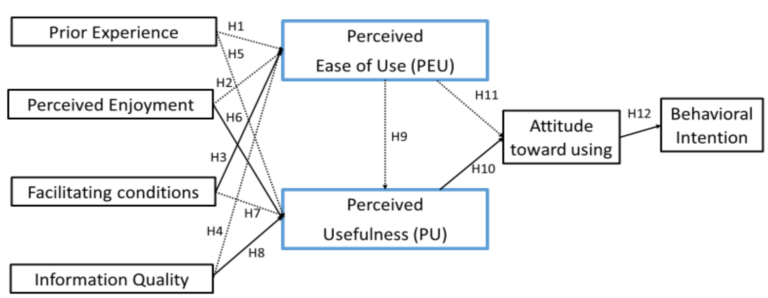

Figure 4. Path diagram results

Table 6. The structural model results.

Hyp	Relation	Beta	Sample mean M	Std dev STDEV	T statis |O/STDEV|	P value	Result
H1	P1 -> PEU	0.133	0.130	0. 068	1.963	0.050	Not Supported
H2	PENJ -> PEU	0.018	0.028	0.120	0.149	0.882	Not Supported

H3	FC -> PEU	0.655	0.642	0.138	4.753	0.000	Supported
H4	IQ -> PEU	0.166	0.178	0.203	0.819	0.413	Not Supported
H5	P1 -> PU	0.121	0.107	0.069	1.746	0.081	Not Supported
H6	PENJ -> PU	0.284	0.279	0.125	2.269	0.023	Supported
H7	FC->PU	0.029	-0.000	0.145	0.200	0.842	Not Supported
H8	IQ ->PU	0.415	0.403	0.176	2.353	0.000	Supported
H9	PEU -> PU	0.163	0.210	0.186	0.875	0.381	Not Supported
H10	PU -> ATT	0.723	0.711	0.123	5.880	0.000	Supported
H11	PEU -> ATT	0.147	0.158	0.130	1.133	0.257	Not Supported
H12	ATT-> BI	0.909	0.908	0.023	40.050	0.000	Supported

As shown in Table 6 and Table 7, ATT had a significant and strong effect on BI (β=0.909, P=0.000). R^2 value was 0.826, which means that 82.6% variance of BI was explained by ATT. PU had a significant and strong effect on ATT (β=0.723, P=0.000) and the 68.5% variance was explained by this construct. However, PEU have no effect on ATT. In addition, PENJ (β=0.248, P=0.023) and IQ (β=0.415, P=0.000) had a significant effect on PU. These constructs explained the 70.8% variance of PU, where IQ explained the most compared to PENJ. IQ exerts about 1.5 as much direct effect on PU as does PENJ (0.284 vs. 0.415). FC was the only construct significantly and strongly affecting PEU (β=0.655, P=0.000). This construct explained the 69.2% variance of PEU. IQ, P and PENJ had no effect on PEU. P had no effect on either PEU or PU.

Table 7: The variance results.

Dependent Variable	R^2	Antecedents	Path Coefficient	Explained Variance %
Perceived ease of use	0.692	H1: P H2: PENJ H3:FC H4:IQ	0.133 0.018 0.655 0.166	9.46 1.28 46.63 11.81 **69.2**
Perceived usefulness	0.708	H5:P H6: PENJ H7:FC H8:IQ H9: PEU	0.121 0.284 0.029 0.415 0.163	8.46 19.86 2.02 29.03 11.40 **70.8**
Attitude toward usage	0.685	H10: PU H11: PEU	0.723 0.147	56.92 11.57 **68.5**
Behavioral intention	0.826	H12: ATT	0.909	90.9

Discussion

Usefulness had a significant and strong impact on students' attitude toward usage of virtual labs. Our findings are consistent with those of Davis et al. (1989) which state that usefulness is more influential than ease of use in driving usage attitude. In other words, the more students feel that virtual labs are useful, the stronger the intention to use virtual labs will be in the future. The significance of virtual labs' usefulness is such that users might be willing to endure a complex virtual lab interface if it offers features that facilitate their learning. This understanding can mitigate the risk of students rejecting virtual labs, providing designers with valuable insights to design more effective virtual labs.

Information quality had a significant and strong direct effect on usefulness and had an indirect effect on attitude. This finding confirms prior studies revealing that information quality positively affects usefulness and attitude. Future research is needed to examine the direct effect of information quality on attitude.

Perceived enjoyment had an indirect effect on attitude as mentioned by Davis (1993) "people use system in part because they enjoy the process of using them". So, enjoyment can be considered a motivation to use virtual labs. This finding is in line with the literature regarding the acceptance of e-learning and more specifically virtual labs, like the result of Estriegana et al. (2019) who found that "playfulness and enjoyment are crucial to engage learners in the subject matter and the learning process, and to improve motivation and acceptance of virtual laboratories".
Surprisingly, prior experience is the only external variable that had no effect, either directly on ease of use or usefulness, or indirectly on attitude and consequently on behavioral intention. This finding contradicts previous studies that showed prior experience to have an effect on user's ease of use and usefulness. Ajzen and Fishbein (1980) found that "Prior experience is an important determinant of attitude". However, there are several recent studies that indicate that prior experience does not have a significant effect on attitude "because digital technologies are becoming an ordinary part of education" (Mailizar et al., 2021). This temporal gap in the literature −from the 1980s to the 2020s− might explain our findings, as the new generation of "digital natives" (Marc, 2001), on whom our research was conducted, tend to adapt quickly to virtual environments and have no difficulties working online. Another possible reason that can explain this finding is the limited scope of our survey, wherein only a single question was employed to assess this variable.

The results suggest that ease of use had no direct or indirect effect on attitude toward usage of virtual labs. This is inconsistent with Gamo (2018) who found that perceived ease of use had a positive effect on behavioral intention. Nevertheless, few other studies found results similar to ours. The insignificant impact of ease of use on students' attitude to use virtual labs can be explained by the participants that conducted the survey. Engineering students tend to consider ease of use as a less significant factor when using virtual labs. For that reason, this study needs to be generalized to explore other populations.

Conclusion

In summary, the findings suggest that students prioritize perceived usefulness over ease of use. Moreover, information quality and perceived enjoyment emerge as the most significant factors influencing students' acceptance of virtual laboratories. These results offer practical insights for educators and instructional designers in STEM education when developing virtual laboratories.

However, it is crucial to acknowledge the limitations of this study. Further investigations should explore additional external variables, such as motivation and self-efficacy, which may influence usefulness, ease of use, and behavioral intention (Davis et al., 1992). Another limitation of this study is the fact that it does not consider how students' perceptions and intentions may change over time as they gain more experience with virtual labs. Future research could benefit from a longitudinal approach to capture these dynamics, hence providing a more comprehensive understanding of factors affecting virtual lab adoption throughout students' academic progression.

Additionally, there is an unexplored dimension concerning gender inequality within the TAM context. Previous studies (Drašler et al., 2021; Gallego-Gómez et al., 2021) have indeed highlighted differences in female behaviors in TAM, raising the need for further investigating the factor of gender in the context of virtual labs. Finally, it is worth noting that a qualitative survey, complementing this study, was conducted simultaneously, and the collected data will be addressed in future research.

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Appendix A

Prior Experience	P1. I have used virtual labs before this experience.
	P2. When I was in High School, I have used virtual labs.
Perceived Usefulness	PU1. Virtual labs help me understand the concepts.
	PU2. Virtual labs are useful for data analysis and visualization.
	PU3. Overall, virtual labs are useful.
Perceived Ease of Use	PEU1. Learning how to use virtual labs is easy.
	PEU2. I don't need help to complete virtual lab exercises.
	PEU3. It is easy to repeat experiments or procedures.
	PEU4. Overall, It is easy to use virtual labs.
Facilitating conditions	FC1. It is Flexible to access virtual labs from anywhere and at any time.
	FC2. I have the necessary resources (laptop, Internet...) to use virtual labs in learning.
	FC3. Virtual labs provide a user-friendly interface that makes it easy for me to complete tasks.
	FC4. I experienced technical difficulties when using virtual labs.
Information Quality	IQ1. Virtual labs material is informative.
	IQ2. Virtual labs are well designed for learning.
Attitude	A1. I am comfortable using virtual labs.
	A2. I intend to continue using virtual labs in the future.
	A3. Assuming I have access to other virtual labs, I intend to use them.
Behavioral Intention	BI1. I would recommend virtual labs to my friends/classmates.
Perceived Enjoyment	PENJ1. I enjoy using Virtual labs
	PENJ2. Using virtual labs for learning is fun.