The Effect of Digital Technology Integration on Students' Academic Performance through Project-Based Learning in an E-Learning Environment

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Abstract—This study aimed to develop a model to examine how digital technology integration contributes to the enhancement of students' academic performance through project-based learning (PBL) amongst undergraduates in higher education. In this study, the technology acceptance model (TAM) was used as the basic model to explore the digital technology environment in terms of the perceived usefulness, perceived ease of use and attitude towards integrating digital technology and the influence of these factors on undergraduates' learning engagement and academic performance within PBL. Therefore, this study proposed a model comprising factors that assist in addressing the study objective. As the main data collection method, a questionnaire was developed to obtain relevant information regarding digital technology acceptance, PBL, students' learning engagement and academic performance. The study sample comprised 185 undergraduate students who were enrolled in a course that utilised PBL. A quantitative research method via structural equation modelling (SEM) was used to analyse the data. The finding suggested that TAM-related factors and students' learning engagement positively affect their academic performance when digital technology is integrated into the PBL environment.

Keywords—Digital technology, academic performance, project-based learning, technology integration, e-learning

1 Introduction

The integration of digital technology has gradually replaced traditional learning environment in educational settings. Today, numerous technological tools and applications are made available for teachers to employ in their classrooms [1]. Digital technology integration in teaching and learning has been found to be associated with enhancing the effectiveness of knowledge construction and distribution along with improving academic performance. However, if digital technology is not properly and systematically integrated into teaching and learning, its impact will not be as expected [2].

In the context of higher education, the use of digital technology forms an integral part of the contemporary student experience [3], [4]. As such, related literature has focused on the potential use of various digital technologies to enable, extend and even improve learning achievement and, consequently, students' overall academic performance [5]-[8]. Henderson et al. [6] studied university students' engagement with digital technologies and explored their actual experiences of digital technology use during their academic studies, highlighting students' perceptions towards important aspects of digital technology when studying and learning. They surveyed 1,658 undergraduate students, and the result of their study highlighted 11 useful characteristics of digital technologies, such as ease of organising and managing tasks, flexibilities of time and place, the ability to replay and revisit teaching materials and learning in more visual forms, to name a few.

Project-based learning (PBL) is one of the pedagogical approaches underpinned by the constructivist learning theory, which views learning as a natural process wherein meaning is constructed by students through interactions and reflections of ideas and experiences [9]. PBL is defined as 'learning that is focused on projects that engage students in investigations more specifically it allows students to learn by pursuing solutions through asking questions, debating ideas, designing plans and communicating with others' [10]. The PBL approach is advocated in the literature for its effectiveness in increasing students' motivation and engagement to learn whilst enhancing their academic performance [11]. PBL has a great educational potential to achieve meaningful learning experiences through collaborative work in the classroom as well as active involvement in the learning process social interaction and knowledge construction [12]-[14]. This dynamic interaction involves attitudes that facilitate support and the stimulation of students by both their own classmates and their teachers, which has an impact on their motivation and, ultimately, their academic performance [15].

Incorporating digital technologies in the design and implementation of PBL is widely implemented across all disciplines [16]. Blumenfeld et al. [17] argued that technology can contribute to how students find projects interesting and significant. Technology can enhance challenge, variety and choice by providing multiple levels of tasks to match student knowledge and proficiency; improve access to numerous sources of information that allow breadth in project questions; and offer many possibilities for product production. Furthermore, technology has the potential to enhance student motivation and support active learning during the various phases of the projects. Gómez-Pablos et al. [7] investigated PBL through the incorporation of digital technologies and collected data from 310 teachers regarding their opinions, and found that the majority of teachers indicated that the projects promoted active participation by students (95%), motivated them to learn (96%) and helped them to acquire various curricular skills (90%). Digital technologies have undeniably made a significant contribution to the task of providing the necessary tools to optimise PBL [1]. Therefore, integrating technologies through PBL can strengthen interactivity, make collaboration smoother and facilitate tasks that are authentic and meaningfully engaging [18], [19]. Thus, incorporating digital technologies is often of great potential in the application of the PBL model.

Therefore, this study attempts to investigate what factors of digital technology integration might contribute to the enhancement of students' learning engagement and the improvement of their academic performance and how the PBL environment contributes to facilitate the process. The present study intends to contribute to the literature by examining the factors that influence students' decision to use or accept digital technology integration when learning in a PBL environment, through the technology acceptance model (TAM), and the effect of these factors on both students' learning engagement and academic performance. Therefore, this study aims to address the following main research question:

How does digital technology integration in PBL affect students learning engagement and academic performance? How are the factors of TAM (perceived ease of use, perceived usefulness, and attitudes toward integrating) contribute to this affect?

Accordingly, three sub-research questions are formulated as following:

- What is the relationship between students' perceived ease of use of digital technology integration and their learning engagement and academic performance in PBL environment?
- What is the relationship between students' perceived usefulness of digital technology integration and their learning engagement and academic performance in PBL environment?
- What is the relationship between students' attitudes toward digital technology integration and their learning engagement and academic performance in PBL environment?

2 Literature Review and Hypotheses Development

This study attempts to explain the conceptual model proposed in Figure 1, which presents the impact of digital technology integration in PBL on students' learning engagement and academic performance via the TAM. Digital technology integration variables (constructs) include perceived ease of use (PEU), perceived usefulness (PU), attitudes towards integration (AI), project-based learning (PBL), students' engagement (SE) and students' academic performance (AP). The variables included in the conceptual model (as shown in Figure 1) are divided into three types. Independent Variables are the influencing variables from which paths (or arrows) only come out, and these include two variables (PEU, PU). Mediator Variables are the influencing and affected variables wherein paths (arrows) either exit or enter. These include PBL, SE and AI. The Dependent Variable (AP) is affected by the independent and mediator variables and can only receive paths (arrows) that enter them.

The TAM is one of the most cited models in explaining attitudes towards technology use [20], such as integrating digital technologies. Amongst the many variables that may influence technology use, Davis [21] suggests two determinants that are especially important. The first is perceived usefulness, which is defined as 'the degree to which a person believes that using a particular system would enhance his or her job performance'. The second path is perceived ease of use, which refers to 'the degree to which a person believes that using a particular system would be free of effort' [21, p. 320]. According to the TAM, perceived usefulness and perceived ease of use are the two major factors that influence rejection or acceptance of technology. Both have been found to positively influence respondents' attitudes towards technology use, which then influence their behavioural intention of using the technology [22]. Despite the fact that some researchers claimed that attitude towards usage of systems mediate the impact of perceived ease of use and perceived usefulness on behavioural intention [20], according to Davis et al. [23], perceived usefulness may directly affect behavioural intention to use technology regardless of one's attitude towards the system.

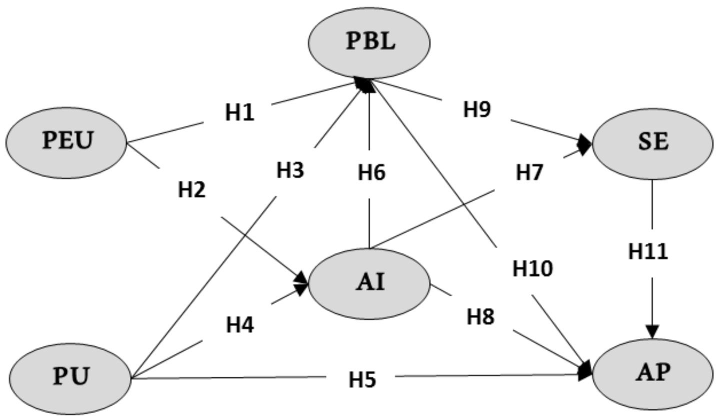

Fig. 1. Conceptual model

Considerable research has been done on the variables proposed in the theory of reasoned acceptance, which deals with users' acceptance and rejection of technology use through their perceptions of the usefulness and ease of technology use [20], [24], [25]. With the increased shift towards PBL as a learner-centred approach in the teaching and learning context and the potential of digital technology integration, the application of the PBL model entails an examination of the extent to which the factors of usefulness, ease of use and attitudes towards the integration of digital technologies through PBL contribute to the enhancement of students' learning engagement and academic performance. In this context, the TAM determines two basic factors of user acceptance of digital technology; PU and PEU as the primary factors of students' AI within PBL. In this study, the model examines these two factors that directly affect students' AI in PBL. The model also explores how these factors influence SE which, in turn, affect the AP of the students. Hence, the following hypotheses are proposed:

- H1: PEU has a positive effect on PBL
- H2: PEU has a positive effect on AI
- H3: PU has a positive effect on PBL
- H4: PU has a positive effect on AI
- H5: PU has a positive effect on AP.

Brown et al. [26] argued that when technology is meaningfully integrated into the teaching and learning environment, students' attitudes are positively influenced towards being more motivated and engaged; therefore, they move beyond knowledge and comprehension to the application and analysis of information. Attitude, which is defined by Weissman and Beck [27, p. 5] as individual's 'tendency to evaluate an object, or a symbol in a certain way', mostly shapes the behaviours of the students [26]. According to Karaçalli and Korur [28] students' attitudes affect both their critical thinking and their level of collaboration in learning. In the PBL approach, students' achievement increases by raising their desire to learn, that is, their attitudes towards learning [29]-[31]. Students' interests and attitudes about a particular topic or domain can greatly influence their performance, thus increasing their achievement and their motivation to continue learning in that area [28].

Research on attitudes about PBL suggest that the PBL approach is positively associated with students' interest and enjoyment of the experience of participating in authentic projects; moreover, they always find value in doing tasks associated with PBL courses [26], [30], [32]-[35]. Perrault and Albert [36] claimed that active learning through PBL may enhance certain attitudes of students, which can ultimately have an impact on their future positive and sustainable behaviours. Beier et al. [37] examined the effectiveness of PBL courses on students' attitudes, major choices and career aspirations with a relatively large sample of students who have either taken at least one PBL course and students who have not. They found that engaging in at least one PBL course during the first four semesters affected students' perceptions of their skills and of the utility value of participating in such courses. Lima et al. [38] assessed students' attitudes about PBL in an engineering course and found that, generally, PBL is positively received and taught students' skills associated with communication and project management, which they would not normally acquire in engineering courses. Furthermore, the benefits of PBL include improved attitudes toward learning and the subject matter itself [30], [31], [39]. On the basis of the above discussion, the following hypothesis are proposed:

- H6: AI has a positive effect on PBL
- H7: AI has a positive effect on SE
- H8: AI has a positive effect on AP

In the related literature, PBL has been advocated for enhancing students' interest and attitudes towards learning and their curiosity to pursue further education [40]. Through the PBL approach, students are meaningfully engaged when trying to solve a problem by searching, analysing, evaluating and synthesising knowledge [39], [41]. 'Students become more engaged in learning when they have a chance to dig into complex, challenging, and sometimes even messy problems that closely resemble real life' [42, p. 298]. One of the significant benefits of PBL is authenticity [43], which enhances students' motivation to learn, promotes critical thinking and meaningful learning and creates a self-regulated learner who is committed to complete the required learning tasks successfully [44], [45].

A vast number of empirical studies that investigated the effectiveness of PBL in higher education settings indicated a positive association with improved students' motivation, engagement, achievement and overall academic performance [10], [13], [14], [28], [40], [46]-[48]. Bilgin et al. [34] investigated the effects of the PBL method on undergraduate students' achievement and its association with their self-efficacy beliefs about science teaching and opinions about PBL. They concluded that students who studied with PBL produced better performance and expressed mostly positive opinions about the use of the PBL method. Meanwhile, Egilmez et al. [11] studied the use of PBL in teaching stimulation for undergraduate and graduate students and surveyed the effectiveness of PBL based on the course learning outcomes. The results indicated that the proposed PBL approach is effective in improving students' learning experience and provided critical support for achieving the intended learning outcomes. In addition, Yusof and Song [49] investigated students' engagement and utilisation of PBL in an e-learning environment through blended learning and reported students' positive response, positive engagement and better performance.

Many studies have shown that PBL is an efficient teaching strategy to enhance students' learning motivation and help them to actively engage in the learning activities [50]. Lee et al. [51] argued that PBL is a favoured pedagogical strategy for encouraging students to engage in self-determined learning whilst developing a range of skills and abilities that are integral to the profession. In summary, evidence of the potential of PBL approach, especially in terms of facilitating learning achievement and motivation of students, is well documented in prior studies [50]. Therefore, the following hypothesis are proposed:

- H9: Integrating digital technology in PBL has a positive effect on SE
- H10: Integrating digital technology in PBL has a positive effect on AP

Learning engagement, which refers to the active participation of students in their learning process [20], has been demonstrated to positively affect the learning experience quality [40]. Warnock and Duncan [52] stated that student engagement must be in centre of the learning process. In higher education learning, meaningful student engagement is achieved by providing 'experimental opportunities to empower and encourage students to devote greater time, energy' and effort towards the designed activities to enhance learning [53, p. 197]. All these aspects can be achieved in PBL as Iwamoto et al. [54] argued that PBL is an innovative approach wherein students drive their own learning through inquiry, standards alignment and collaborative research. A study by Nielsen et al. [55] to examine the effect of the PBL on students' cooperative learning and attitudes found that PBL is an effective teaching model for engineering education students. The engineering students were able to achieve process skills, they were more motivated to learn and actively engaged in the outside sources to accomplish the requirements of the project. Moreover, PBL has the potential to enhance students' motivation and attitudes, learning skills, learning engagement, academic achievement [31], [56]-[59]. Therefore, the final hypothesis is proposed as following:

- H11: SE has a positive effect on AP.

3 Research Methods

Current study aimed to develop a conceptual model to assess the effect of digital technology integration on students' academic performance in a PBL environment. Therefore, a quantitative approach using a survey questionnaire instrument was used.

3.1 Setting and sample

The participants of the current study were female bachelor's degree students from the Faculty of Education, who were taking a compulsory course on Computers in Education (TE304). The students came from different majors, including Childhood Education, Special Needs Education, Educational Technology and Art Education, with various levels of digital technology understanding and experience. At the beginning of the semester, they were introduced to the PBL approach wherein the tasks and requirements were clearly explained to them. The PBL represented 40% of the final course assessment. To accomplish the course project successfully, students were required to work collaboratively and utilise various forms of digital technologies (e.g. animations, augmented reality, social media, mobile Apps, Blackboard, etc.) in each step of their PBL (e.g. plan, design, development and delivery of their projects). At the end of the semester, after 14 weeks of using integrated digital tools and applications, the students were invited to complete a paper-based questionnaire to reflect on their perceptions towards their experiences.

3.2 Data collection and measurement

Data were collected amongst eight classes of students (n = 200) taking the same subject (TE304). Questionnaires were distributed to 200 students, of whom 185 agreed to respond to the questionnaire; thus, the response rate was 92% of the intended population. According to Hassan [60], the appropriate sample size should not be less than the number of variables multiplied by 20 (p. 462). Since this study has six variables (PEU, PU, PBL, SE, AI, AP), the sample size of 185 (6 x 20 = 120 < 185) is more than sufficient for current study.

The survey questionnaire, which was administrated manually to the 185 participants, consisted of 33 items that were measured by a 5-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree and 5 = strongly agree). The collected data were entered and tabulated in SPSS v. 23. Then, in order to examine the proposed conceptual model, the structural equation modelling (SEM) method available in the LISREL8.8 programme was used. The survey questionnaire instrument featured the six constructs proposed in the conceptual framework in Figure 1. To ensure content validity, the questionnaire items were adopted from previous studies (shown in Table 1) and minor modifications were made to address the context of this study. Table 1 shows the source of all constructs in the research model along with the number of items in each construct (the questionnaire items of all constructs are shown in the Appendix).

Table 1. Constructs in the research measurement

Constructs	Measures	
	# of Items	***Source***
PEU	5	Weng *et al*. [24]
PU	5	Weng *et al*. [24]
AI	4	Weng *et al*. [24]
AP	6	Papaioannou [61]
SE	7	Krause and Coates [62]
PBL	6	Alorda et al [63]

4 Data Analysis

4.1 Participants' demographic information

Table 2 lists the demographic information concerning participants' gender, age and academic major. As shown in Table 2, participants were undergraduate level studying bachelor degree at the time of this research. 97.3% were between 18 and 20 years old and 2.7% were between 21 and 23 years old. Most participants specialized in Childhood Education (53%), while 34% of them specialized in Educational Technology. Relatively small percentage of participants were specialized in Special Needs Education (8.1%) and Art Education (4.3%).

Table 2. Participants demographic information

Characteristic	Number	%
Gender		
Male	0	0
Female	185	100
Total	185	100
Age		
18-20 years old	180	97.3
21-23 years old	5	2.7
Total	185	100
Academic Major		
Childhood Education	98	53
Educational Technology	64	34.6
Special Needs Education	8	4.3
Art Education	15	8.1
Total	185	100

4.2 Measurement model analysis

In analysing the data, a two-step procedure according to Hair et al. [64] were followed. First, the measurement model to measure reliability and validity was examined. Second, the structural model (SEM) was applied to investigate the direction and strength of the relationships between the theoretical model constructs.

The reliability of the research instrument which consisting of six constructs was calculated using Cronbach's alpha coefficient in order to measure the internal consistency between the items of each construct. The result in Table 3 shows the reliability values of all six constructs (PEU, PU, PBL, SE, AI, AP) were ranging from 0.77 to 0.83 (all surpassed the cut-off-value of 0.7) [60]. The result in Table 3 also shows the composite reliability values of all the six constructs were ranging from 0.85 to 0.90 (all surpassed the cut-off-value of 0.7) [64].

Table 3. Reliability and convergent validity analysis

Constructs	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
PEU	0.80	0.87	0.58*
PU	0.83	0.89	0.61*
AI	0.77	0.85	0.60*
AP	0.78	0.88	0.57*
SE	0.77	0.90	0.58*
PBL	0.82	0.86	0.57*

*AVE > 0.5

To construct validity of the measurement model, convergent validity was examined by calculating the Average Variance Extracted (AVE) from the constructs. Table 3 shows that the AVEs of all the six constructs passed the recommended value of 0.5 [64]. To verify the discriminant validity, the square root of the AVE for all constructs were calculated and used to compare with the correlations between constructs [64]. Table 4 shows that all the square roots of the AVEs are greater than the pairwise correlations involving the constructs.

Table 4. Discriminant validity

Constructs	PEU	PU	AI	AP	SE	PBL
PEU	**0.76**					
PU	0.50	**0.78**				
AI	0.67	0.53	**0.78**			
AP	0.58	0.52	0.66	**0.75**		
SE	0.42	0.30	0.42	0.52	**0.76**	
PBL	0.47	0.35	0.51	0.57	0.66	**0.75**

4.3 Structural model analysis

After the measurement model was confirmed, the SEM was implemented as the main statistical technique to analyse data. Specifically, the SEM method available in the LISREL8.8 programme was used to obtain the causal model that illustrates the effects (direct and indirect) amongst the current study theoretical constructs, which are included in the conceptual model illustrated in Figure 1. The overall goodness of fit using fit indices (X2, df, X2/df, RMR, IFI, CFI and RMSEA) were assessed. The results of the LISREL8.8 programme indicated that the SEM (causal model) in Figure 2 had good goodness of fit indicators (shown in Table 5), wherein the value of X2 was not statistically significant, and the values of all indicators fell within the acceptable range for each indicator. This indicates a good fit of the model with the data being tested [60].

It can be seen from Table 5 that key statistics of the conceptual model were very good. Therefore, the conceptual model of this study is valid, and the result of the hypotheses should be analysed.

Table 5. Goodness of fit statistics for the causal model

No.	Index	Value	Acceptance Range of Index	Best Value of Index [60]
1	Chi-Square X^2 df P (Sg.)	6.09 3 0.11	X^2 is not statistically significant	0
2	X^2 / df	2.03	(0) to (5)	0
3	Goodness of Fit Index (GFI)	0.99	(0) to (1)	1
4	Adjusted Goodness of Fit Index (AGFI)	0.92	(0) to (1)	1
5	Root Mean Square Residual (RMR)	0.02	(0) to (0.1)	0
6	Root Mean Square Error of Approximation (RMSEA)	0.08	(0) to (0.1)	0
7	Expected Cross-Validation Index (ECVI) for Causal Model ECVI for Saturated Model	0.23 0.23	(ECVI) for Causal Model ≤ ECVI for Saturated Model	
8	Normed Fit Index (NFI)	0.99	(0) to (1)	1
9	Comparative Fit Index (CFI)	1.00	(0) to (1)	1
10	Relative Fit Index (RFI)	0.96	(0) to (1)	1
11	Incremental Fit Index (IFI)	1.00	(0) to (1)	1

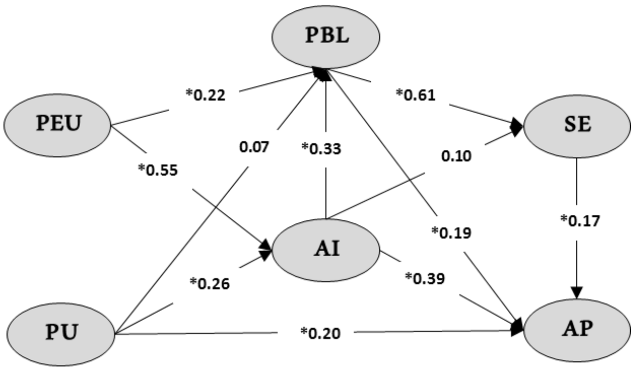

Fig. 2. Structural Equation Model (Causal Model, *asterisk represents significant paths)

4.4 Result of hypotheses testing

The result of previous analysis supports the conceptual framework, thus confirming the hypotheses regarding the directions and relationships between the conceptual model constructs. Table 6 shows the direct, indirect and total effects included in the

SEM (causal model), combined with the T-values and standard errors of the effect estimate as well as the statistical significance of the effect.

Table 6. The direct, indirect and total effects included in the SEM

	Kind of Effect		Influencing Variables				
			PEU	***PU***	***AI***	***PBL***	***SE***
PBL	**Direct**	Effect	0.22	0.07	0.33		
		Sd. Error	0.09	0.08	0.09		
		T Value	2.52*	0.92	3.76**		
	Indirect	Effect	0.18	0.09			
		Sd. Error	0.05	0.03			
		T Value	3.48**	2.83**			
	Total	Effect	0.40	0.16	0.33		
		Sd. Error	0.07	0.07	0.09		
		T Value	5.36**	2.08*	3.76**		
SE	**Direct**	Effect			0.10	0.61	
		Sd. Error			0.06	0.06	
		T Value			1.60	9.55**	
	Indirect	Effect	0.30	0.12	0.20		
		Sd. Error	0.06	0.05	0.06		
		T Value	5.29**	2.45*	3.50**		
	Total	Effect	0.30	0.12	0.30	0.61	
		Sd. Error	0.06	0.05	0.08	0.06	
		T Value	5.29**	2.45*	3.92**	9.55**	
AI	**Direct**	Effect	0.55	0.26			
		Sd. Error	0.06	0.06			
		T Value	9.10**	4.31**			
	Total	Effect	0.55	0.26			
		Sd. Error	0.06	0.06			
		T Value	9.10**	4.31**			
AP	**Direct**	Effect		0.20	0.39	0.19	0.18
		Sd. Error		0.06	0.06	0.07	0.07
		T Value		3.44**	6.07**	2.74**	2.66**
	Indirect	Effect	0.34	0.15	0.12	0.11	
		Sd. Error	0.05	0.04	0.03	0.04	
		T Value	6.84**	3.77**	3.38**	2.56*	
	Total	Effect	0.34	0.35	0.51	0.30	0.18
		Sd. Error	0.05	0.06	0.06	0.06	0.07
		T Value	6.84**	5.52**	7.80**	5.11**	2.66**

Sd. Error = standard error of estimate
*Statistically significant ($p > 0.05$) ** Statistically significant ($p > 0.01$)
If 1.96 > T Value > 2.58 is statistically significant ($p > 0.05$)
If 2.58 ≤ T Value is statistically significant ($p > 0.01$)

Table 6 above and Figure 2 indicate statistically significant direct and indirect relationships with total positive effects ($\beta 1 = 0.40$, $t = 5.36$, $p > 0.01$) between students' PEU of digital technology on the use of the PBL approach. This means that the greater the students' PEU of digital technology integration, the more positive they are about learning through this approach using digital technology in both direct and indirect ways. The indirect effect of PEU on learning through the PBL approach was achieved through the mediator variable: students' attitude towards digital technology integration. This result supports H1, which states that there is a significant relationship between PEU and the integration of digital technology in PBL.

A statistically significant indirect relationship with total positive effect ($\beta 1 = 0.30$, $t = 5.29$, $p < 0.01$) between students' PE of digital technology use and SE with digital technology integration in PBL. This means that students increasingly engaged with digital technology when they find that integrating this digital technology is easy to use through a PBL environment. Meanwhile, the indirect effect of PEU on SE is achieved by two mediator variables: PBL and AI. This means that students' PEU of digital technology integration has a positive effect on AI through PBL which, in turn, has a positive effect on SE.

In addition, a statistically significant indirect relationship exists with a total positive effect ($\beta 1 = 0.34$, $t = 6.84$, $p > 0.01$) between students' PEU of digital technology integration and their AP. This means that the greater the students' PEU of digital technology integration, the greater their AP in an indirect way. The indirect effect of students' PEU of digital technology integration on their AP is achieved by two mediator variables: PBL and AI. There is also a statistically significant direct relationship with a total positive effect ($\beta 1 = 0.55$, $t = 9.10$, $p > 0.01$) between students' PEU of digital technology on AI within the PBL environment. This means that the greater the students' PEU of digital technology use, the greater their AI in the PBL environment. Hence, H2 is supported.

Meanwhile, the direct effect of students' PU of digital technology integration on their learning through the PBL approach is positive but not statistically significant. In comparison, there exists a statistically significant indirect relationship with total positive effects ($\beta 1 = 0.09$, $t = 2.83$, $p > 0.01$) between student's PU of digital technology integration and their learning through the PBL approach. This means that the greater the students' PU of digital technology integration, the more positive they perceived their learning through the PBL approach. Hence, H3 is supported.

In addition, a statistically significant indirect relationship with a total positive effect ($\beta 1 = 0.12$, $t = 2.45$, $p > 0.05$) exists between students' PU of digital technology integration and their SE in PBL. This means that the greater the students' PU of digital technology integration, the greater the SE in their learning through PBL. The indirect effect of PU on SE was achieved through two mediator variables: PBL and AI.

Another statistically significant direct relationship with a total positive effect ($\beta 1 = 0.26$, $t = 4.31$, $p > 0.01$) is found between students' PU of digital technology integration and AI through PBL. This means that the greater the students' PU, the more they have a positive attitude toward digital technology integration in PBL. This provides strong support for H4. Likewise, statistically significant direct and indirect relationships with total positive effects ($\beta 1 = 0.12$, $t = 2.45$, $p > 0.01$) are found between students' PU of digital technology integration and their AP through PBL environment. This means that the greater the students' PU in PBL, the greater the improvements in their AP in a direct way. Meanwhile, the indirect effect of PU on students' AP is achieved by two mediator variables: PBL and AI. These results support H5.

In addition, a statistically significant direct relationship with a total positive effect ($\beta 1 = 0.33$, $t = 3.76$, $p > 0.01$) exists between students' AI and their learning through the PBL approach. This means that the greater the students' AI, the greater their perception of learning in a PBL approach. These results support H6, which states that students' AI has a positive effect on their attitudes towards learning through the PBL approach. The direct effect of AI on SE is positive but not statistically significant. However, there exists a statistically significant indirect relationship with a total positive effect ($\beta 1 = 0.20$, $t = 3.50$, $p > 0.01$) between students' AI and SE. This means that the greater the students' AI in PBL, the greater the SE in their learning in an indirect way. The indirect effect of AI on SE is achieved by one mediator variable: PBL. Thus, H7 is supported, which posits a significant relationship between AI and SE.

There are statistically significant direct and indirect relationships with total positive effects ($\beta 1 = 0.51$, $t = 7.80$, $p > 0.01$) between students' AI and their AP in PBL. This means that the greater the students' AI, the better their AP in a PBL environment in both direct and indirect ways. The indirect effect of AI on AP is achieved through two mediator variables: PBL and SE. Thus, H8 is supported.

A statistically significant direct relationship with a total positive effect ($\beta 1 = 0.61$, $t = 9.55$, $p > 0.01$) exists between PBL and SE. This means that the more the students utilise digital technology through the PBL approach, the greater the SE in their learning in a direct way. This result supports H9, which assumes the positive effect of utilising digital technology in PBL on SE. Likewise, there are statistically significant direct and indirect relationships with total positive effects ($\beta 1 = 0.30$, $t = 5.11$, $p > 0.01$) between PBL and students' AP. This means that the more the students utilise digital technology through the PBL approach, the greater the improvement in their AP in direct and indirect ways. The indirect effect of PBL on AP is achieved through one mediator variable: SE. Thus, H10, which highlights the positive and significant effect of PBL on students' AP, is supported.

Finally, a statistically significant direct relationship with total positive effects ($\beta 1 = 0.18$, $t = 2.66$, $p > 0.01$) exists between SE and AP. This means that the greater the SE in utilising digital technology through the PBL approach, the greater the improvements in their AP. Thus, H11, which assumes a positive and significant effect of SE on AP, is supported.

5 Discussion

The results highlight that the relationships between digital technology integration and PEU, PE, AI and SE help improve the academic performance of undergraduate students through a PBL environment. These results are supported by the TAM literature [21] wherein PEU and PE are the two important factors that positively or negatively influence individual behaviours towards technology—directly and indirectly—through the influence of individuals' attitudes towards technology use. With a learner-centred approach, such as PBL, students construct their knowledge in an interactive and collaborative learning environment. Through various projects, students engage in investigations by asking questions, debating on ideas, designing plans and communicating with others [10, p. 46]. The useful characteristics of digital technologies offer great potential to support students' learning within a PBL environment [6]. The results of this study confirm the notion that the use of digital technology in PBL facilitates flexible and quick communication (useful), which results in an effective interaction and collaboration between students and their peers and the successful completion of their projects. Likewise, the ease of organising and managing of learning tasks (ease of use) along with the ability to access, reply and revisit materials anytime and anywhere (ease of use, usefulness) motivate students to actively participate in their learning and consequently generate a positive attitude towards learning, thereby resulting in better academic performance.

In addition, the study results support the idea that digital technology integration in PBL positively influences students' learning engagement. The results indicate that the increased use of digital technology through PBL increases students' learning engagement and, ultimately, their academic performance. Indeed, digital technology, through PBL, facilitates authentic and meaningfully engaging learning tasks [18], [19]. Digital technology can enhance challenge, variety and choice by featuring multiple levels of tasks to match students' individual knowledge and proficiency, providing access to numerous sources of information that allow breadth in project tasks and offering many possibilities to support knowledge production [17]. The result of the effect of students' engagement on their academic performance when utilising digital technology in PBL is supported by a number of studies [11], [49], [57], [59].

6 Implications and Limitations

Pedagogical implications of this study results suggest that digital technologies should be systematically and appropriately designed and integrated in all of the projects' stages (e.g., planning, designing, implementation and evaluation) when determining PBL for undergraduate students. That is, if digital technologies are easy to use, students are more likely to engage in meaningful learning and achieve better learning outcomes [6]. Moreover, orienting and familiarising students to the useful characteristics of the determined digital technologies and their potential influence on facilitating learning tasks and improving overall performance can increase students' motivation and their behavioural attitudes towards accepting and effectively using digital technologies in various learning practices and aspects which, in turn, would reflect positively in their academic performance. Therefore, in selecting and designing learning tasks in PBL, university instructors and course designers should carefully consider various digital technology tools and applications, which are user-friendly and can effectively and efficiently facilitate the teaching of the required learning tasks.

Given the results of this study on the importance of integrating digital technologies in PBL and their significant impact on raising the level of students' engagement and academic performance [11], [18], [19], [59], we present a number of recommendations for instructors as follows. First, if certain digital techniques are identified for students and are required to use in PBL, instructors must ensure that students possess the required skills in order to ensure easy usage of these digital technologies in learning. Consequently, students must be trained on how to use and maximise these digital technologies in project completion; the necessary technical support for students must be provided if needed. Second, instructors should consider providing flexibility for students in selecting alternatives to digital technologies from those determined by the course instructor. Such flexibility will allow them to determine which technologies they find easier to use or are more useful in accomplishing the project tasks. This ensures that the students can have better learning engagement and optimal academic performance in a PBL environment.

Certain limitations should be considered when interpreting the results. First, the study was conducting within a limited setting of female students from a particular collage (Education Collage) taking the same course (Educational Technology). The situation in other contexts might reveal different results. Therefore, future research should examine the robustness of the findings across different settings (e.g., male and female students from different colleges). Second, the result of this study was based on a conceptual model of TAM-related factors. Future research should consider the extended TAM model and examine external factors such as student's technological competency and teacher support that might contribute to the conceptual space of digital technology integration and PBL environment.

7 Conclusion

The purpose of this study was to investigate what factors of digital technology integration contribute to the enhancement of students' learning engagement and the improvement of their academic performance and how a PBL environment contributes to facilitate this process. Therefore, a conceptual model, which consists of six constructs, PEU, PU, AI, PBL, SE and AP, was proposed and examined. We hypothesised that students, through the PBL approach, will accept and become more motivated to use digital technologies, which are perceived as easy to use and useful, so that they can successfully accomplish their learning tasks. We also proposed that students will be more meaningfully engaged in the PBL approach if they utilised digital technology that are easy to use and useful for their learning. These interrelated relationships contribute positively to enhancing students' academic performance. The results highlight that the relationships between digital technology integration and perceived ease of use, perceived usefulness, attitude towards integration and students' engagement, help improve the academic performance of undergraduate students through a PBL environment.

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11 Appendix

Questionnaire Items

Perceived Ease of Use

1. I find it easy to integrate digital technologies in PBL in my class.
2. Integrating digital technologies in PBL is easy and understandable.
3. My interaction with digital technologies in PBL is easy and flexible.
4. I find it easy to learn through integrating digital technologies in PBL.
5. It is easy to become skillful in integrating digital technologies in PBL.

Perceived Usefulness

1. Integrating digital technologies in PBL in my class enables me to accomplish tasks effectively.
2. Integrating digital technologies in PBL in my class improves the learning performance.
3. Integrating digital technologies in PBL increases my productivity.
4. Integrating digital technologies in PBL makes it easier for me to learn.
5. Integrating digital technologies in PBL is useful for my learning.

Attitude toward Integrating

1. Integrating digital technologies in PBL has a positive influence in learning.
2. Integrating digital technologies in PBL makes learning more interesting.
3. Integrating digital technologies in PBL is fun.
4. I like learning with integrating digital technologies in PBL.

Academic Performance

1. Integrating digital technologies in PBL helps me to learn by myself.
2. Integrating digital technologies in PBL helps me to improve my technological skills.
3. Integrating digital technologies in PBL helps me to design effective learning content.
4. I feel very satisfied when I learn new knowledge and skills in PBL through integrating digital technologies.
5. I enjoy trying my best to learn skills through integrating digital technologies in PBL.
6. What I learn through Integrating digital technologies in PBL makes me want to practice more.

Students' Engagement

1. Integrating digital technologies in PBL makes me go through my project and make sure that it is right.
2. Integrating digital technologies in PBL makes me try to understand my mistakes when I get something wrong.
3. Integrating digital technologies in PBL makes me put more effort into learning.
4. Integrating digital technologies in PBL makes me keep trying even if something is hard.
5. Integrating digital technologies in PBL makes me look forward to finish my project successfully.
6. Integrating digital technologies in PBL makes me feel excited when I am doing my project.
7. Integrating digital technologies in PBL makes me try to work with others who can help me.

Project Based Learning (PBL)

1. Integrating digital technologies in PBL increases the motivation for the subject.
2. Integrating digital technologies in PBL is important for interaction with other groups.
3. Integrating digital technologies in PBL contributes to accomplish the course goals.
4. Integrating digital technologies in PBL makes it very important to accomplish the project tasks.
5. Integrating digital technologies in PBL helps in developing the learning process.
6. Integrating digital technologies in PBL increases my motivation towards collaboration.