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High acceptance with limited integration: unmasking the mobile learning paradox in engineering education

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ABSTRACT

Mobile learning has become an important component of digital transformation in higher education; however, its pedagogical integration in engineering education remains unclear. This study investigates the mobile learning paradox, a phenomenon in which high levels of mobile learning acceptance coexist with limited instructional integration. A descriptive quantitative survey was conducted involving 140 students at Universitas Ahmad Dahlan. Data were collected using a validated questionnaire developed from the technology acceptance model (TAM) and technological pedagogical content knowledge (TPACK) frameworks. Descriptive statistics and multiple linear regression were employed to analyze technology acceptance, pedagogical integration, implementation barriers, and factors influencing behavioral intention (BI). The findings reveal relatively high levels of perceived usefulness (PU) (77.2%), self-efficacy (SE) (75.2%), perceived ease of use (PEU) (74.2%), and subjective norm (SN) (74.0%). However, BI remained comparatively lower (72.0%), while the use of mobile technologies for simulation-based and laboratory learning was limited (50.3%). Multiple regression analysis indicated that PEU and SN significantly influenced BI, whereas PU and SE were not significant predictors. Internet instability and limited pedagogical integration were identified as major barriers. These findings provide empirical evidence of the mobile learning paradox and highlight the need for curriculum redesign, structured mobile learning activities, lecturer training, and improved digital infrastructure to support meaningful technology integration in engineering education. Beyond identifying technology acceptance factors, this study introduces empirical evidence of the mobile learning paradox by demonstrating that high student acceptance does not necessarily translate into meaningful pedagogical integration in engineering education.

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1. INTRODUCTION

The rapid advancement of digital technologies has significantly transformed higher education, particularly through the increasing adoption of mobile learning as a flexible and technology-enhanced learning approach [1]–[3]. Mobile technologies enable students to access learning resources anytime and anywhere, support collaborative learning, facilitate self-regulated learning, and promote personalized educational experiences [4]–[7]. As a result, mobile learning has become an increasingly important component of digital transformation initiatives in higher education, supporting the development of more accessible, student-centered, and competency-oriented learning environments [1], [2], [6]. Within engineering education, mobile learning is particularly relevant because it can support active learning approaches, including problem-based learning, project-based learning, simulation-based instruction, and experiential learning, which are essential for developing professional competencies, critical thinking, and problem-solving skills required in modern engineering practice [8]–[11]. Recent studies have reported positive educational outcomes associated with mobile learning adoption, including improved student engagement, learning motivation, academic performance, and learning flexibility [3], [12]–[14]. Despite these benefits and the growing availability of mobile technologies, questions remain regarding whether high levels of mobile learning acceptance are accompanied by meaningful pedagogical integration within engineering teaching and learning practices [10], [11], [15].

Previous studies have consistently demonstrated the educational benefits of mobile learning across various higher education contexts [3], [12], [13], [16]. Research has shown that mobile learning enhances student engagement, learning motivation, academic achievement, self-regulated learning, and flexibility in accessing educational resources [5], [12]–[14]. In engineering and science, technology, engineering, and mathematics (STEM) education, mobile technologies have been implemented through diverse instructional approaches, including blended learning, flipped classrooms, augmented reality (AR), virtual reality (VR), microlearning, and interactive multimedia applications [14], [15], [17]–[23]. These approaches have been reported to support conceptual understanding, critical thinking, practical skill development, and collaborative learning experiences, particularly in laboratory-based and problem-solving learning environments [8], [11], [15], [18], [23], [24]. From a theoretical perspective, the technology acceptance model (TAM) remains the most widely adopted framework for explaining students' acceptance of mobile learning technologies [25]. Previous studies have consistently identified perceived usefulness (PU), perceived ease of use (PEU), self-efficacy (SE), and subjective norm (SN) as significant predictors of behavioral intention (BI) to use mobile learning technologies [26]–[32]. While these studies provide valuable insights into the factors influencing technology adoption, most focus primarily on students' acceptance, readiness, and intention to use mobile technologies [28]–[36]. Comparatively less attention has been given to examining whether such positive perceptions are translated into meaningful pedagogical integration within actual engineering teaching and learning practices, particularly within engineering learning environments that emphasize laboratory activities, simulations, and problem-solving processes [10], [11], [15].

Despite the growing body of evidence supporting mobile learning adoption in higher education, several important gaps remain unresolved. First, a theoretical gap exists because most previous studies have primarily examined technology acceptance and BI using frameworks such as the TAM, with limited attention given to how technology acceptance is translated into actual pedagogical integration [28]. As a result, current literature provides a strong understanding of why students are willing to adopt mobile learning technologies but offers less insight into how these technologies are meaningfully incorporated into teaching and learning processes. Second, a contextual gap remains within engineering education. Although mobile learning has been widely investigated across various educational settings, relatively few studies have explored its implementation in engineering programs, which possess distinctive characteristics such as laboratory-based instruction, technical simulations, project-based activities, and competency-oriented learning [11]. Third, a practical gap can be observed between the increasing acceptance of mobile learning technologies and their actual use in engineering pedagogy. While students generally report positive perceptions regarding the usefulness and ease of use of mobile technologies [29], the effective classroom integration of mobile devices remains dependent on instructional design, learning activities, and institutional support [37]. These technologies are often utilized primarily for communication, information access, and administrative learning purposes rather than for supporting simulation-based learning, laboratory activities, and engineering problem-solving [14]. This discrepancy reflects a phenomenon that may be described as the "mobile learning paradox," in which high levels of mobile learning acceptance coexist with limited pedagogical integration. Understanding this paradox is important because the success of digital transformation initiatives in engineering education should not be evaluated solely through technology adoption rates but also through the extent to which mobile technologies contribute to meaningful learning experiences and competency development [1]. Therefore, further empirical investigation is required to examine the relationship between technology acceptance, BI, pedagogical integration, and implementation barriers in engineering education, thereby providing a more comprehensive understanding of mobile learning adoption and its educational impact.

In response to these gaps, this study aims to investigate the integration of mobile learning technologies in engineering education and to provide empirical evidence regarding the mobile learning paradox. Specifically, the study seeks to identify the types of mobile technologies used by engineering students, examine the frequency of their use and students' perceptions of their effectiveness, and explore the challenges associated with their implementation in learning activities. Furthermore, the study examines the factors influencing students' BI to use mobile learning technologies by analyzing the roles of PU, PEU, SE, and SN [28]. By simultaneously investigating technology acceptance, BI, pedagogical integration, and implementation barriers, this study seeks to provide a more comprehensive understanding of how mobile learning technologies are adopted and utilized within engineering education contexts.

To address the identified gaps, this study employs a quantitative survey approach that integrates constructs from the TAM and the technological pedagogical content knowledge (TPACK) framework. While TAM is used to examine factors influencing students' BI to adopt mobile learning technologies, TPACK provides a lens for evaluating the extent to which these technologies are pedagogically integrated into engineering learning environments. The main contribution of this study lies in its simultaneous examination of technology acceptance, BI, pedagogical integration, and implementation barriers within a single analytical framework. Unlike previous studies that predominantly focused on students' willingness to adopt mobile technologies [28]–[32], this research investigates whether high levels of acceptance are accompanied by meaningful instructional integration. In doing so, the study advances the concept of the mobile learning paradox by empirically demonstrating the discrepancy between technology acceptance and pedagogical implementation in engineering education. This contribution extends existing mobile learning research and provides a more comprehensive perspective on digital transformation by moving beyond adoption indicators toward evaluating the educational value of technology integration in teaching and learning practices [1], [3], [13].

The significance of this study extends to both theoretical and practical domains of engineering education. From a theoretical perspective, the study contributes to the advancement of mobile learning and technology acceptance research by extending existing understanding beyond students' acceptance and BI toward the pedagogical integration of mobile technologies. Through the investigation of the mobile learning paradox, the study provides a conceptual and empirical explanation of why high levels of technology acceptance do not necessarily lead to meaningful instructional implementation. From a practical perspective, the findings offer valuable implications for educators, researchers, policymakers, and higher education institutions. For engineering educators, the results can support the design of more effective teaching practices through structured mobile learning activities that promote active learning, collaboration, self-directed learning, and competency development [8], [10]. For curriculum developers and institutions, the findings provide evidence for redesigning curricula that integrate mobile learning into learning outcomes, instructional strategies, assessment systems, and competency-based engineering education [15].

The study also highlights opportunities to strengthen simulation-based learning and laboratory activities through the integration of mobile-accessible simulations, AR, VR, and virtual laboratory environments that facilitate the connection between theoretical concepts and practical applications [17], [22], [24]. Furthermore, the findings support the development of mobile-enhanced problem-based learning environments that encourage collaborative problem solving, project coordination, information sharing, and reflective learning beyond classroom boundaries [10]. At the policy level, the results may inform decisions related to digital infrastructure investment, lecturer professional development, learning management system (LMS) enhancement, and the development of high-quality mobile learning content [2], [38]. Consequently, this study contributes not only to the advancement of mobile learning theory but also to the improvement of engineering teaching practices, curriculum innovation, and institutional strategies that support more effective, contextualized, and sustainable digital transformation in higher education.

2. METHOD

2.1. Research design

This study employed a descriptive quantitative research design using a cross-sectional survey approach to investigate the adoption and pedagogical integration of mobile learning technologies in engineering education. A survey method was considered appropriate because it enables the systematic collection of data from a relatively large number of participants and facilitates the examination of students' perceptions, experiences, and BI regarding mobile learning. The study was designed to explore the phenomenon referred to as the "mobile learning paradox", namely the coexistence of high levels of mobile learning acceptance and limited pedagogical integration in engineering learning environments. Specifically, the survey was used to identify the types of mobile technologies utilized by students, examine their frequency of use, assess perceptions of usefulness and ease of use, evaluate the extent of pedagogical integration, and investigate barriers that may hinder the effective implementation of mobile learning. This quantitative approach also enabled statistical analysis of the relationships among key constructs derived from the TAM, thereby providing empirical evidence to address the study objectives and research hypotheses.

2.2. Research instrument

The research instrument consisted of a structured questionnaire developed based on constructs derived from the TAM and the TPACK framework. TAM was employed to examine students' acceptance of mobile learning technologies through five key constructs, namely PU, PEU, SN, SE, and BI. These constructs were selected because they have been widely recognized as significant predictors of technology adoption and usage behavior in mobile learning environments. In addition, the TPACK framework was incorporated to evaluate the extent to which mobile technologies were pedagogically integrated into engineering learning activities. The TPACK-related items focused on students' perceptions of technology integration in instructional practices, learning activities, and engineering content delivery. All questionnaire items were adapted from validated instruments reported in previous mobile learning and educational technology studies and were contextualized to engineering education settings. Responses were measured using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). To enhance methodological transparency and reproducibility, Table 1 presents the mapping between the TAM and TPACK constructs and the corresponding questionnaire items used in this study.

Table 1. Mapping of TAM and TPACK constructs to questionnaire items

Framework	Construct	Questionnaire item
TAM	PU	Mobile learning improves my learning performance.
TAM	PEU	Mobile learning applications are easy to use.
TAM	SN	People important to me encourage the use of mobile learning.
TAM	SE	I am confident in using mobile learning technologies.
TAM	BI	I intend to continue using mobile learning in the future.
TPACK	Technological knowledge (TK)	I can effectively operate mobile learning technologies.
TPACK	Technological pedagogical knowledge (TPK)	Mobile technologies support learning activities and interaction.
TPACK	Technological content knowledge (TCK)	Mobile technologies help me understand engineering concepts.
TPACK	Technology integration	Mobile technologies are integrated into engineering learning activities.

2.3. Instrument validation

Prior to the main data collection, the questionnaire underwent a rigorous validation process to ensure its content validity, clarity, and reliability. First, the instrument was reviewed by three experts consisting of two specialists in educational technology and one expert in engineering education. The expert review focused on the relevance, clarity, and appropriateness of the questionnaire items in measuring the intended constructs within the context of engineering education. Based on their recommendations, several items were revised to improve wording, readability, and contextual suitability. Following the expert review, a pilot study was conducted involving 30 engineering students who were not included in the final research sample. The pilot testing aimed to evaluate item clarity, response consistency, and the overall usability of the online questionnaire. Feedback obtained from the pilot participants was used to refine several statements and improve the questionnaire structure before large-scale distribution.

The reliability of the instrument was subsequently assessed using Cronbach's alpha coefficient. The results indicated satisfactory internal consistency across all constructs, with Cronbach's alpha values exceeding the recommended threshold of 0.70. Specifically, the alpha coefficients were 0.86 for PU, 0.84 for PEU, 0.82 for SN, 0.88 for SE, 0.85 for BI, and 0.87 for the TPACK-related pedagogical integration construct. These results demonstrate that the instrument possessed adequate reliability and was suitable for subsequent data collection and statistical analysis.

2.4. Sampling strategy

This study employed a purposive sampling technique to ensure that the selected participants possessed relevant experience with mobile learning technologies in engineering education. Purposive sampling was considered appropriate because the study specifically targeted students who had sufficient exposure to mobile technology–supported learning activities and were therefore capable of providing informed responses regarding technology acceptance, BI, and pedagogical integration. To meet this objective, participants were required to satisfy the following criteria: i) being active students enrolled in Electrical Engineering, Informatics Engineering, or Vocational Teacher Education in Electronics programs at Universitas Ahmad Dahlan; ii) having completed at least two semesters of study; and iii) owning and utilizing a mobile device for academic purposes. These criteria ensured that respondents had adequate experience with both engineering learning environments and mobile learning technologies, thereby enhancing the relevance of the collected data to the research objectives.

Nevertheless, several potential sources of sampling bias should be acknowledged. Since the study was conducted within a single institution, the findings may not fully represent engineering students in other universities or educational contexts. Furthermore, students who actively participated in the survey may have been more familiar with digital technologies and more inclined to use mobile learning tools than non-participants, potentially introducing self-selection bias. Although these limitations may affect the generalizability of the findings, purposive sampling remains appropriate for exploratory investigations of technology adoption and pedagogical integration within a specific educational context. The final sample consisted of 140 respondents. The adequacy of the sample size was evaluated based on the recommendation of Tabachnick and Fidell [39], which suggests a minimum sample size of $N>50+8m$ for multiple regression analysis, where m represents the number of independent variables. Since this study included four independent variables (PU, PEU, SN, and SE), the minimum required sample size was 82 respondents. Therefore, the sample size of 140 exceeded the recommended threshold and was considered adequate for conducting multiple linear regression analysis and hypothesis testing.

2.5. Survey distribution and ethical considerations

Data collection was conducted using an online questionnaire administered through Google Forms. The survey link was distributed through multiple official communication channels, including class WhatsApp groups, institutional email lists, and the university's LMS, to maximize participant reach and accessibility. The data collection period lasted for two weeks, during which students were invited to voluntarily participate in the study. Responses were screened to ensure completeness and consistency before proceeding to the statistical analysis stage.

Ethical considerations were carefully addressed throughout the study. Prior to participation, respondents were provided with information regarding the purpose of the study, the voluntary nature of participation, data confidentiality, and their right to withdraw from the survey at any time without penalty. Informed consent was obtained electronically before respondents could access the questionnaire. Furthermore, the study complied with the ethical principles of educational and social research and received approval from the relevant academic authority at Universitas Ahmad Dahlan before data collection was undertaken.

2.6. Regression assumption testing

Prior to conducting the multiple linear regression analysis, several diagnostic tests were performed to verify that the data satisfied the underlying assumptions of regression. First, the normality assumption was assessed by examining the distribution of regression residuals using the Shapiro–Wilk test and normal probability plots. The results indicated that the residuals were approximately normally distributed ($p>0.05$), suggesting that the normality assumption was satisfied. Second, multicollinearity among the independent variables was evaluated using variance inflation factor (VIF) and tolerance values. All predictor variables exhibited VIF values below the recommended threshold of 5.0 and tolerance values above 0.20, indicating the absence of serious multicollinearity issues. Third, the homoscedasticity assumption was examined using residual scatterplots and the Breusch–Pagan test. The results revealed no significant heteroscedasticity ($p>0.05$), indicating that the variance of residuals remained relatively constant across predicted values. Collectively, these diagnostic results confirmed that the dataset met the required assumptions for multiple linear regression analysis, thereby supporting the validity and reliability of the subsequent statistical findings.

2.7. Research procedure

To improve methodological transparency and facilitate reproducibility, the overall research procedure is illustrated in Figure 1. The study was conducted through several sequential stages, beginning with questionnaire development based on the TAM and TPACK framework. The instrument subsequently underwent expert validation and pilot testing to ensure content validity, clarity, and reliability. Following the validation process, the online questionnaire was distributed to eligible participants through institutional communication channels. The collected responses were screened and verified before being subjected to descriptive statistical analysis, regression assumption testing, and multiple linear regression analysis. This systematic procedure ensured the rigor of the data collection and analysis processes while providing a clear framework for investigating the mobile learning paradox in engineering education.

As shown in Figure 1, the research procedure consisted of instrument development, validation, data collection, and statistical analysis stages. This structured process ensured that the findings were derived from a valid and reliable dataset and that the analytical procedures were conducted systematically to address the research objectives. The procedure also enhances methodological transparency and facilitates future replication of the study. Furthermore, it provides a comprehensive framework for investigating the mobile learning paradox by examining both technology acceptance and pedagogical integration within engineering education contexts.

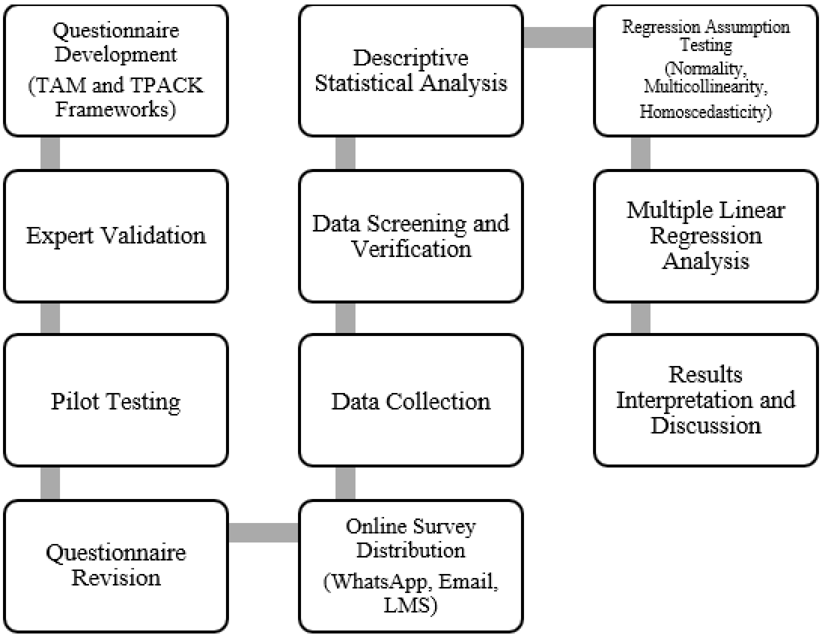


Figure 1. Research procedure

2.8. Study limitations

Several limitations of this study should be acknowledged when interpreting the findings. First, the study was conducted at a single institution, namely Universitas Ahmad Dahlan, which may limit the generalizability of the results to other engineering education contexts, universities, or countries with different technological infrastructures and learning environments. Second, the study relied on self-reported data collected through questionnaires. Although self-report measures are widely used in technology acceptance research, respondents' perceptions and evaluations may be influenced by social desirability bias, personal interpretations, or inaccuracies in recalling their actual mobile learning experiences. Consequently, the reported levels of technology acceptance, BI, and pedagogical integration may not fully reflect actual learning practices. Third, the study employed a cross-sectional research design, capturing students' perceptions at a single point in time. As a result, the findings do not provide evidence regarding changes in mobile learning adoption, BI, or pedagogical integration over time. Longitudinal studies would be valuable for examining how students' perceptions and usage behaviors evolve as mobile learning technologies become more deeply embedded within engineering education. Despite these limitations, the study provides important insights into the mobile learning paradox and contributes to a better understanding of the relationship between technology acceptance and pedagogical integration in engineering education.

3. RESULTS AND DISCUSSION

3.1. Description of respondents

A total of 140 respondents participated in this study. Figure 2 presents the demographic characteristics of the respondents based on gender, study program, semester, and mobile device operating system. Overall, the respondent profile shows that the participants were predominantly male students, were mainly enrolled in the informatics engineering program, were mostly in the 4th or 6th semester, and primarily used Android-based mobile devices for learning activities. The detailed distribution of each respondent characteristic is presented in Figure 2(a)–(d). Figure 2(a) shows that the majority of respondents were male (77.9%) and aged 19 to 23 years. Figure 2(b) indicates that more than half of the respondents were enrolled in the informatics engineering program (57.9%), followed by electrical engineering (25%) and vocational teacher education in electronics (17.1%). Figure 2(c) shows that most respondents were in their 4th or 6th semester. Figure 2(d) indicates that all respondents owned mobile devices, with 73.6% using Android-based devices and 26.4% using iOS-based devices. These characteristics provide a descriptive profile of the respondents and confirm that the sample comprised students from engineering-related programs with experience using mobile devices for academic purposes.

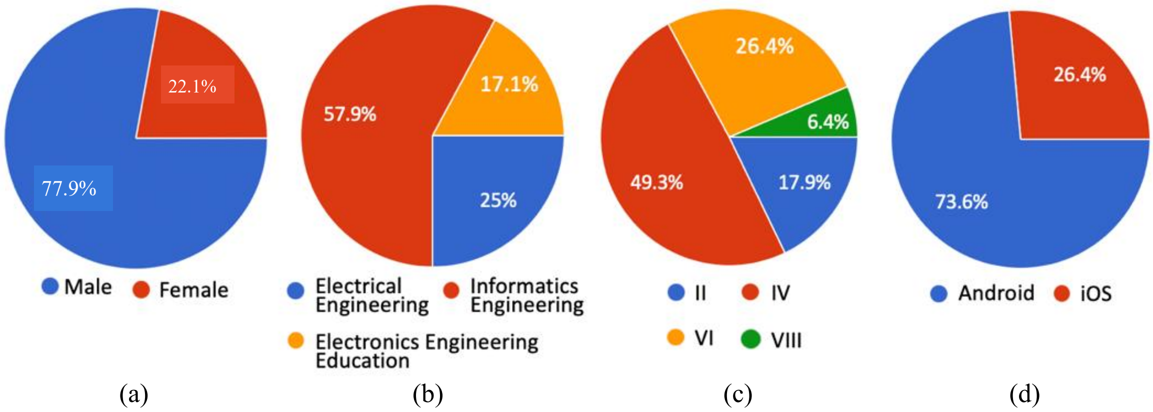


Figure 2. Description of respondents based on: (a) gender profile; (b) department; (c) semester; and (d) the operating system of the devices

Figure 3 presents the frequency of mobile technology use for learning activities among the respondents. The figure consists of two subfigures: Figure 3(a) presents the average score (AS) for each type of mobile technology use, while Figure 3(b) presents the distribution of respondents' responses on the 5-point Likert scale. Overall, mobile technology was used more frequently for learning interaction, access to instructional videos, and online discussion, whereas its use for accessing academic references and running simulation applications was comparatively limited. Figure 3(a) shows that learning interaction achieved an AS of 3.91 (78.1%), exceeding the cut-off threshold of 3.75 (75%). These activities were supported by applications such as Zoom Meetings, Google Classroom, and LMS-based platforms. This finding indicates that mobile technology is primarily used to facilitate communication and interaction between lecturers and students. Access to instructional videos also exceeded the cut-off, with an AS of 3.84 (76.9%). The highest score was recorded for online discussion at 4.51 (90.3%), indicating frequent use of mobile technology for interaction between students and lecturers and among students. This fact is understandable, as effective interaction among learning components is a fundamental prerequisite for creating meaningful learning experiences. In emergencies when face-to-face meetings are not feasible, Church *et al.* [40] note that STEM students tend to prefer online meetings via Zoom to no meetings at all. The response distribution indicates higher levels of use for learning interaction and online discussion, while lower levels were observed for academic reference access and simulation-based activities. Access to academic references recorded an AS of 3.71 (74.1%), slightly below the cut-off, suggesting that mobile technology has not yet been fully utilized to support independent academic information seeking. The lowest score was recorded for simulation applications, at 2.51 (50.3%), indicating limited use of mobile technology for experimental and laboratory-based learning.

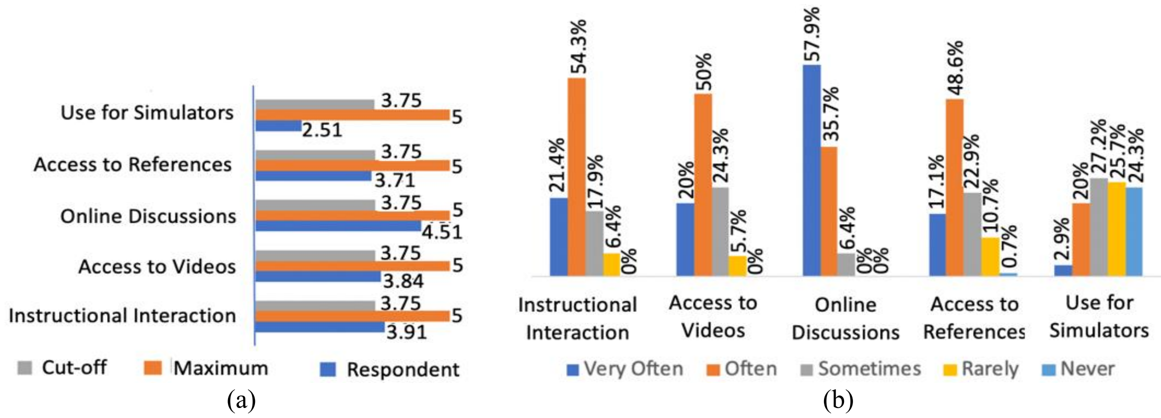


Figure 3. Frequency of mobile technology usage for learning: (a) AS and (b) distribution of responses

Additionally, applications to access instructional videos received a high score of 3.84 (76.9%), exceeding the cutoff. This finding suggests that students extensively use video platforms, such as YouTube and massive open online courses (MOOCs), as primary sources for learning materials in engineering. The highest score was recorded for online discussion activities, at 4.51 (90.3%). This result reflects a high level of student participation in online discussions with both lecturers and fellow students. Such interactions are generally facilitated through mobile applications like WhatsApp and Telegram, which play a crucial role in supporting the smooth progression of their learning processes. This condition is understandable, given that lecturers at the university where this study was conducted have recognized online discussion as an effective method for fostering student collaboration and enhancing learning effectiveness. Thus, this method is widely implemented in daily teaching practices [41].

The study revealed that students' use of mobile learning to access references remains suboptimal, as indicated by an AS of 3.71 (74.1%), which falls below the established threshold of 3.75 (75%). Such a result is understandable, given that most respondents were in the early to mid-stages of their studies and had not yet reached the thesis or final project phase, which typically demands a higher intensity of academic reference search and utilization. In addition, students may still rely on learning materials provided directly by lecturers rather than independently exploring scholarly sources through mobile platforms. This finding suggests that the educational potential of mobile learning for supporting academic information literacy and self-directed knowledge acquisition has not yet been fully realized among engineering students.

As shown in Figure 3, the use of mobile devices for running simulation applications scored only 2.51 (50.3%), falling short of the minimum threshold. This suggests that mobile technology in engineering education is primarily used for information access and communication, rather than for experimental or simulation-based laboratory activities. The pattern reflects the limited adoption of simulator applications by lecturers in teaching engineering subjects, which prevents students from fully experiencing the potential of mobile learning to support practical activities through mobile-based virtual laboratories. Such limitations are understandable, as laboratory implementation must consider inclusivity and accessibility. Nevertheless, identifying accessible features and developing virtual laboratories for diverse learners remain complex challenges [42].

3.2. Perception of mobile technology acceptance

Understanding students' perceptions toward mobile learning is essential for evaluating the factors that influence technology adoption in educational settings. Positive perceptions of a technology do not necessarily guarantee its consistent use in learning activities, making it important to examine both acceptance and BI. These perceptions provide valuable insights into students' readiness to engage with mobile learning technologies and may help explain the extent of their integration into engineering education. Based on the collected data, the analysis of respondents' perceptions—covering the variables of PU, PEU, SE, SN, and BI in the use of mobile technology for learning are presented in Figure 4.

The perception analysis yielded an overall AS of 74.5% across all variables of mobile technology acceptance, indicating a relatively high level of acceptance for its use in learning. In the PU aspect, respondents assigned the highest score of 3.86 (77.2%), as shown in Figure 4(a). Figure 4(b) presents the distribution of perceptions on a Likert scale for each aspect of mobile technology acceptance. These findings suggest that respondents consider mobile learning highly beneficial in enhancing their knowledge of engineering-related subjects.

For the PEU, SN, and SE, respondents scored 3.71 (74.2%), 3.70 (74%), and 3.76 (75.2%), respectively, as shown in Figure 4(a). Although the first two scores did not reach the acceptance threshold, they were close to it. These results indicate that respondents generally demonstrate a good level of acceptance toward mobile learning, particularly due to its ease of use, their confidence in using it (SE), and social support (SN), especially encouragement from lecturers. Overall, these findings indicate that mobile technology has been well-received by engineering students. This fact aligns with previous studies reporting high levels of mobile learning acceptance among university students in South Africa [43], Taiwan [26], and Malaysia [44].

Based on Figure 4(a), among all measured aspects, BI obtained the lowest score at 3.6 (72%), falling below the acceptance threshold. Figure 4(b) shows that the perception distribution for this aspect leans toward disagreement. The lower score for BI relative to other aspects suggests that, although students acknowledge the benefits, ease of use, lecturer support, and self-confidence in using mobile technology for learning, their commitment to continued use remains constrained. The obstacles include limited infrastructure, a preference for conventional learning methods, lecturer readiness, insufficient availability of mobile-based content, and potential distractions from mobile device usage. Furthermore, institutional policies that have yet to fully support the integration of mobile learning also contribute to students' low intention to continue using this technology in the future.

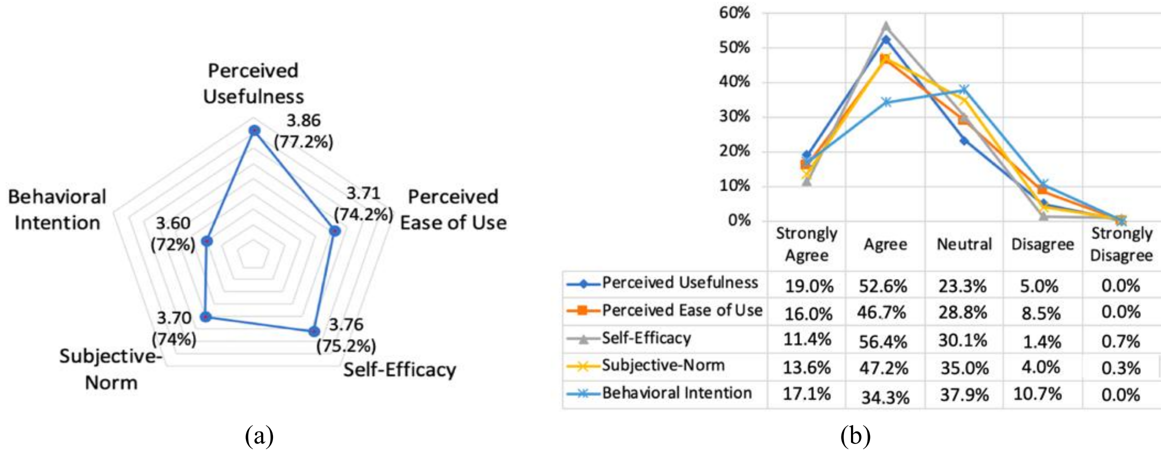


Figure 4. Perceptions of mobile technology acceptance: (a) AS and (b) distribution of responses

3.3. Pedagogical integration of mobile technology

While the previous analysis focused on students' acceptance of mobile learning technologies, acceptance alone does not necessarily indicate meaningful use within instructional practices. Therefore, it is important to examine the extent to which mobile technologies are integrated into teaching and learning activities, particularly within the context of engineering education where practical, laboratory-based, and problem-solving activities play a central role. Based on the data analysis, the study participants' responses regarding the pedagogical integration of mobile technology in engineering education are presented in Table 2.

Table 2. Perceptions regarding the integration of mobile technology in engineering education

Name of aspect	Likert score					AS (%)
	STA (%)	A (%)	N (%)	D (%)	STD (%)	
Lecturer usage	10.7	48.6	37.1	2.9	0.7	3.66/73.2
Concept linkage	11.4	56.4	30.0	1.5	0.7	3.76/75.3
Theory-practice	11.4	56.4	27.2	5.0	0.0	3.74/74.8
Device suitability	12.9	46.4	28.7	12	0.0	3.60/72.0
Lecturer support	16.4	45.7	32.9	5.0	0.0	3.74/74.8

STA: strongly agree; A: agree; N: neutral; D: disagree; STD: strongly disagree

Referring to Table 2, the majority of respondents indicated that the use of mobile technology in learning has not yet been fully integrated pedagogically. Although students were able to associate mobile technology with understanding engineering concepts (AS=3.76 or 75.3%), utilize it to integrate theoretical knowledge and practical skills (AS=3.74 or 74.8%), and receive support from lecturers in using mobile technology for learning (AS=3.74 or 74.8%), only 59.3% of respondents stated that their lecturers actively use mobile media in classroom instruction. The remainder were either uncertain or disagreed that lecturers had actively incorporated mobile devices into their teaching. Additionally, only about 59.3% of students agreed that mobile technology is suitable for engineering education, while the remainder were uncertain or disagreed.

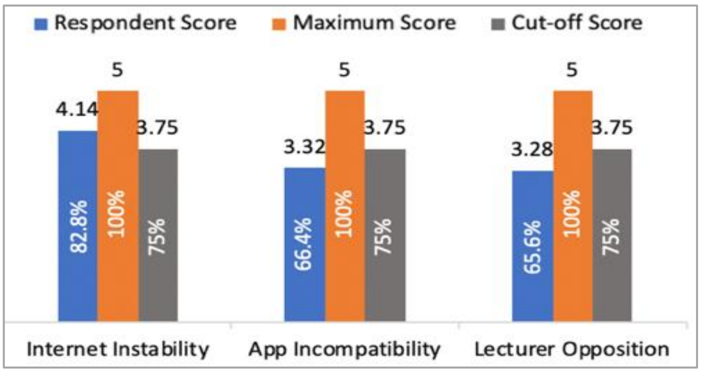
These findings highlight that lecturers' digital literacy and the still sporadic design of mobile learning remain key challenges to the pedagogical integration of mobile technology in engineering education. Furthermore, the implementation of mobile learning faces additional constraints, including a lack of localized content for mobile educational applications, technical issues with wireless network coverage, insufficient educator preparedness, and equipment costs [45]. To maximize the potential of mobile learning, institutions must address technological infrastructure challenges, provide training for educators, and refine digital learning strategies [46].

Addressing these challenges would greatly benefit the process of integrating mobile technology into pedagogical systems, particularly in engineering education. Ramli *et al.* [46] further note that integrating mobile technology into engineering learning through LMS has proven to be a practical approach for enhancing educational quality. Additionally, mobile-based learning enhances student performance, engagement, and motivation while supporting flexible, accessible education across all student levels, particularly in higher education. The integration of mobile technology into pedagogy also increases student interest in learning, supports the development of digital literacy, and strengthens students' learning resilience [47].

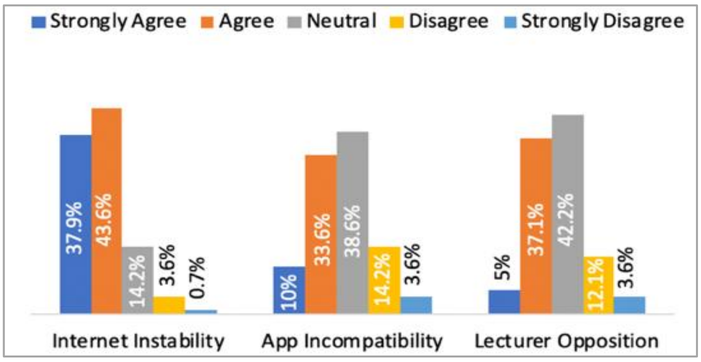
3.4. Barriers to the use of mobile technology

In addition to examining technology acceptance and pedagogical integration, it is also important to identify the challenges that may hinder the effective implementation of mobile learning in engineering education. Understanding these barriers can provide valuable insights into why high levels of technology acceptance do not always translate into meaningful instructional integration. The results of the data analysis on barriers to the use of mobile technology—covering internet instability, app compatibility, and lecturer support—are presented in Figure 5.

Referring to Figure 5(a), the analysis of students' perceptions regarding barriers to the use of mobile technology in learning shows that, although students feel they have received sufficient support from lecturers and most learning applications meet their needs, internet instability remains the most significant perceived barrier, with a percentage of 82.2%. This figure far exceeds the 75% threshold, indicating that unstable internet connectivity is the most critical challenge to implementing mobile learning on campus. Consequently, even when students demonstrate positive attitudes toward mobile learning, inadequate technological infrastructure may limit its effective and consistent integration into educational activities. Figure 5(b) shows the distribution of responses on perceptions of barriers to mobile technology use.



(a)



(b)

Figure 5. Perceptions of barriers to mobile technology use: (a) AS and (b) distribution of responses

This finding is consistent with previous research indicating that limited internet connectivity and funding are the most common obstacles for universities in adopting mobile technology for learning, particularly in developing countries such as Greece [48], Tanzania [49], South Africa [50], Iraq [51], and Botswana [43]. Even in developed countries such as Russia, internet connectivity issues remain a significant challenge [45]. In line with earlier studies, the present research recommends that local governments provide adequate internet infrastructure to support the integration of mobile technology into university-level learning. This study also identified an interesting finding regarding students' comfort preferences when using mobile devices or laptops, as shown in Figure 6. This preference gap poses a challenge of equal importance to other barriers to integrating mobile technology into engineering pedagogy.

A total of 65% of students agreed or strongly agreed that they feel more comfortable using non-mobile devices, such as laptops, compared to mobile devices, as shown in Figure 6(a). Students also reported difficulties in understanding engineering materials when relying solely on mobile devices, as illustrated in

Figure 6(b). This situation indicates that although students have received substantial support from lecturers and have found many learning applications suitable, there remain unmet needs that mobile technology has yet to address.

These findings are consistent with previous research, which noted that existing mobile learning applications have not fully accommodated the diverse needs of all learners [52]. To address this challenge, adoption strategies are needed to enhance student learning performance by leveraging more effective mobile learning applications. Furthermore, improving the functionality and adaptability of mobile learning platforms may facilitate more meaningful integration of mobile technologies into engineering teaching and learning activities.

Figure 6. Student preferences for non-mobile device use: (a) comfort and (b) understanding difficulty

3.5. Factors influencing behavioral intention

This study also aimed to identify the variables that contribute to the formation of BI. The data analysis in this step uses multiple linear regression, beginning with a simultaneous correlation test of all independent variables (X1, X2, X3, and X4) with the dependent variable (Y). This analysis was conducted to determine the extent to which each predictor variable contributes to students' intention to adopt and utilize mobile learning technologies. Table 3 presents a summary of the regression test results.

Table 3. Summary of multiple regression analysis

Source	df	Sum of square	Mean square	R^2	F	p
Regression	4	74.9968	18.7492	0.6488	62.3386	0.0000
Residual	135	40.6032	0.3008	-	-	-
Total	139	115.6	0.83166	-	-	-

Referring to Table 3, the data analysis yielded an F-value of 62.34 ($p<0.05$). This result indicates that regression analysis rejects the null hypothesis and accepts the alternative hypothesis, concluding that there is a statistically significant simultaneous correlation between all independent variables (X1, X2, X3, and X4) and the dependent variable (Y). These findings demonstrate a strong and significant collective influence of PU (X1), PEU (X2), SE (X3), and SN (X4) on BI (Y). Based on the coefficient of determination (R^2) value of 0.65, the independent variables in this study account for 65% of the variance in BI. In comparison, other factors outside the scope of this research model influence the remaining 35%.

However, when viewed from the perspective of partial contributions, the variables differ in their relative influence, as shown in Table 4. PEU (X2) made the most considerable effective partial contribution at approximately 23.41%, followed by PU (X1) at 19.95%, SN (X4) at 15.09%, and SE (X3) at 6.56%. These results suggest that ease of use is the primary factor influencing students' intention to use mobile technology in engineering education. The results indicate that SN plays an important role in shaping students' BI toward mobile learning adoption. This finding suggests that students' decisions to use mobile learning technologies are influenced not only by their personal perceptions but also by social expectations and support from significant others, including lecturers, peers, and the institution. In engineering education, where learning activities are often collaborative and instructor-guided, encouragement from lecturers and the integration of mobile technologies into course activities can strengthen students' willingness to adopt these technologies. Similarly, peer influence may contribute to technology adoption when mobile learning becomes a common practice within learning communities. These findings are consistent with previous studies that highlight the importance of social influence in technology acceptance and suggest that successful mobile learning implementation requires both technological readiness and a supportive educational environment.

Table 4. Partial effective contribution and significance of variables

Variable	Partial correlation (r)	Significance (p)	Significance status	% effective contribution
X1	0.7212	>0.05	Not significant	19.95
X2	0.7775	<0.05	Significant	23.40
X3	0.4515	>0.05	Not significant	6.56
X4	0.6044	<0.05	Significant	15.09

Although PU (X1) demonstrated a relatively large partial contribution, its statistical effect on BI was not significant (p>0.05). This finding suggests that perceived benefits alone are insufficient to shape the intention to use mobile technology unless accompanied by stronger driving factors, such as ease of use or social encouragement. In contrast, PEU (X2) and SN (X4) were found to have significant and effective contributions, positioning them as more reliable predictors of students' BI. The substantial and significant contribution of SN (X4) further indicates that encouragement or expectations from key figures—such as lecturers, peers, and institutions—plays an important role in motivating students to adopt mobile learning. Meanwhile, SE (X3) contributed the least and was statistically insignificant, implying that although students feel capable of using mobile devices, this factor is less decisive compared to ease of use and social support.

The results show that PEU is the strongest and most significant predictor of BI, followed by SN. This finding aligns with previous research [26], [27], which emphasized that ease of use is a key driver of intention to use mobile learning among students. Social support (SN) was also found to have a significant effect, consistent with the findings [26], [53], who reported that pressure or encouragement from lecturers, peers, and institutions has a substantial positive influence on the intention to use mobile technology in learning.

On the other hand, PU in this study showed a strong effect but was not statistically significant. This finding differs from several previous studies [28], [44], which reported that PU has a direct and significant impact on BI. This discrepancy may be due to a mediating effect of ease of use, or to the greater influence of social support variables in the context of engineering students in Indonesia. Meanwhile, SE had the smallest and statistically insignificant contribution to BI. This result is consistent with the findings of Lai *et al.* [54], who noted that although self-confidence in using mobile devices is important, it tends to exert an indirect effect, particularly when students are already accustomed to using digital technologies. Overall, the pattern of results in this study suggests that, in the context of Indonesian engineering students, BI is more strongly influenced by external factors—such as PEU and social support—than by internal factors, including PU and SE. This fact highlights the importance of mobile learning adoption strategies that prioritize enhancing ease of use and fostering social support within engineering learning environments.

Although students generally reported positive perceptions regarding the usefulness and ease of use of mobile learning technologies, BI exhibited a comparatively lower score. This finding suggests that positive perceptions of technology do not automatically translate into a strong intention to use mobile learning as an integral component of learning activities. One possible explanation is that students primarily utilize mobile devices for communication, accessing learning materials, and administrative purposes rather than for deeper instructional activities such as simulations, laboratory exercises, and engineering problem solving. Consequently, while students recognize the benefits of mobile learning, they may not perceive it as an essential tool for achieving core engineering learning outcomes. This finding supports the existence of the mobile learning paradox, whereby technology acceptance is relatively high but pedagogical integration remains limited. The result further indicates that increasing students' intention to use mobile learning requires not only accessible technology but also meaningful learning experiences that demonstrate its value within engineering education contexts.

3.6. Educational implications of the mobile learning paradox

The findings suggest the need for curriculum redesign that incorporates mobile learning as an integral component of engineering education. For example, mobile-accessible simulations can be embedded within laboratory courses to help students visualize engineering processes before conducting practical activities. In addition, assignments can be redesigned to utilize mobile platforms for project monitoring, collaborative problem solving, data collection, and reflective learning. Such curriculum innovations can strengthen the connection between theoretical instruction and authentic engineering practice while enhancing students' digital competencies. The findings of this study indicate that engineering students demonstrate relatively high acceptance of mobile learning technologies; however, their pedagogical integration remains limited. This condition, referred to as the mobile learning paradox, suggests that technology adoption alone is insufficient to transform learning practices unless supported by appropriate pedagogical strategies and institutional initiatives. Therefore, several practical implications can be proposed.

First, higher education institutions should consider redesigning LMS to support more interactive and engineering-oriented learning experiences. Current LMS implementations are often used primarily for distributing learning materials, submitting assignments, and facilitating communication. To enhance pedagogical integration, LMS platforms should incorporate features that support mobile-accessible simulations, virtual laboratories, collaborative project management, real-time feedback mechanisms, and competency-based assessment. Such redesign would enable mobile technologies to play a more active role in engineering learning processes rather than functioning merely as administrative tools.

Second, engineering educators should develop more structured mobile learning activities that are intentionally aligned with learning objectives and pedagogical outcomes. The findings suggest that students frequently use mobile devices for communication and accessing learning resources but rarely for simulation-based learning or engineering problem-solving activities. Consequently, lecturers should design structured learning experiences that integrate mobile technologies into problem-based learning, project-based learning, laboratory preparation, reflective activities, collaborative discussions, and field-based learning tasks. Such activities can help bridge the gap between technology availability and meaningful educational utilization.

Third, the results highlight the importance of professional development programs that strengthen lecturers' competencies in mobile pedagogy integration. Although students generally perceive mobile learning positively, effective integration depends largely on lecturers' ability to design, facilitate, and evaluate technology-enhanced learning experiences. Therefore, institutions should provide targeted training programs focusing on mobile learning design, digital assessment strategies, mobile-supported collaborative learning, simulation-based instruction, and the pedagogical use of emerging technologies such as AR and VR. Strengthening lecturers' pedagogical and technological competencies is essential for transforming mobile devices from communication tools into effective instruments for engineering education.

The mobile learning paradox indicates the need for pedagogical redesign that moves beyond technology adoption toward meaningful instructional integration. One possible strategy is the implementation of blended learning models that combine face-to-face instruction with mobile-supported learning activities. Engineering educators may also integrate AR and VR technologies to provide immersive learning experiences that facilitate conceptual understanding and practical skill development. Furthermore, microlearning approaches can be employed to deliver concise and targeted learning content through mobile devices, allowing students to access instructional materials flexibly while supporting continuous learning engagement.

At the institutional level, the findings highlight the importance of policies that support the pedagogical integration of mobile learning technologies. Universities should consider investing in digital infrastructure, including reliable internet connectivity, mobile-compatible LMS, and access to simulation-based learning resources. In addition, professional development programs should be established to enhance lecturers' competencies in mobile pedagogy and technology-enhanced instruction. Institutions should also encourage the development of high-quality mobile learning content that aligns with engineering curricula and supports competency-based learning outcomes.

The study also emphasizes the importance of interdisciplinary collaboration in the implementation of mobile learning within engineering education. Effective integration requires the convergence of engineering education, informatics, and instructional design. Engineering educators contribute domain-specific knowledge and professional competencies, informatics specialists provide technological solutions and system development expertise, while instructional designers ensure that learning activities are pedagogically meaningful and aligned with learning objectives. Such interdisciplinary collaboration can enhance the effectiveness of mobile learning initiatives and support sustainable digital transformation in engineering education. Collectively, these recommendations emphasize that overcoming the mobile learning paradox requires a holistic approach involving technological infrastructure, instructional design, and lecturer capacity development. Through LMS redesign, structured mobile learning activities, and enhanced lecturer training, institutions can improve the pedagogical integration of mobile learning and maximize its contribution to engineering education outcomes.

4. CONCLUSION

The descriptive analysis shows that engineering students demonstrated a good level of acceptance toward mobile learning in the aspects of PU (77.2%), PEU (74.2%), SE (75.2%), and SN (74%), with the latter three variables approaching or reaching the 75% acceptance threshold. In contrast, BI received the lowest score (72%), indicating that barriers to the sustained use of mobile technology remain. The multiple linear regression analysis revealed that PU, PEU, SE, and SN significantly contributed to BI, with an R^2 of 0.65. However, on a partial basis, only PEU and SN emerged as statistically significant predictors of BI, while PU and SE, despite their practical contributions, were not statistically significant. These findings highlight that, in the context of engineering education, students' intention to adopt mobile learning is more strongly influenced by ease of use and social support than by perceived benefits or self-confidence. Therefore, strategies for integrating mobile technology into engineering education should prioritize enhancing user-friendliness and strengthening social support from lecturers, peers, and educational institutions.

Future research should extend the present study in several directions. First, longitudinal studies are needed to examine how students' acceptance of mobile learning technologies and pedagogical integration evolve over time. Second, cross-country comparative studies could provide insights into how cultural, institutional, and technological factors influence the mobile learning paradox in different educational contexts. Third, experimental studies should be conducted to evaluate the effectiveness of specific mobile learning interventions, such as AR/VR-supported learning, mobile-based laboratory activities, microlearning modules, and blended learning models, in improving pedagogical integration and engineering learning outcomes. These findings contribute to future educational research by providing empirical evidence that technology acceptance should be examined together with pedagogical integration when evaluating digital transformation initiatives in higher education.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
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E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

INFORMED CONSENT

Informed consent was obtained electronically from all participants before they completed the online questionnaire. Participation was voluntary and anonymous, and participants were informed that they could withdraw from the study at any time without penalty.

ETHICAL APPROVAL

This study was conducted in accordance with the ethical principles for educational and social research. Approval to conduct the study was obtained from the relevant academic authority at Universitas Ahmad Dahlan prior to data collection.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available because they contain information that could compromise the privacy of the research participants.

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