

The Role of Project-Based Learning and Mobile Learning in Fostering Student Engagement in TVET

Juli Sardi¹, Darmansyah², Oriza Candra¹, Devi Faizah Yuliana³,
Habibullah^{1*}

¹ Department of Electrical Engineering,
Universitas Negeri Padang, Jl. Prof. Dr. Hamka, Air Tawar Barat, Padang, 25173, INDONESIA

² Department of Educational Technology Curriculum,
Universitas Negeri Padang, Jl. Prof. Dr. Hamka, Air Tawar Barat, Padang, 25173, INDONESIA

³ Department of Ushuludin, Adab, and Da'wah,
IAIN Kerinci, Sungai Penuh, 37112, INDONESIA

*Corresponding Author: habibullah@ft.unp.ac.id
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Abstract

This study examines the role of integrating Project-Based Learning (PjBL) and Mobile Learning (ML) in enhancing Student Engagement (SE) in TVET. Using a quantitative method with an explanatory causal design, this research explores direct and indirect relationships among PjBL, ML, and SE using Structural Equation Modelling (SEM). Data were collected from 40 TVET students enrolled in the Electrical Motor Installation course at Universitas Negeri Padang. The findings reveal that PjBL significantly enhances SE through constructive, independent, collaborative, and contextual learning. Meanwhile, ML amplifies these benefits by providing flexibility, accessibility, and interactive platforms, effectively mediating the impact of PjBL on SE. Together, these approaches address the cognitive, behavioural, and emotional dimensions of engagement, creating a synergistic framework that aligns educational practices with the demands of a technology-driven workforce. The study underscores the importance of integrating PjBL and ML to foster autonomy, real-world relevance, and adaptability in TVET students. The practical implications of this study require educators to utilise these approaches to design dynamic learning experiences, institutions to invest in the necessary technological infrastructure and educator training, and policymakers to support such innovations through targeted policies and resources.

1. Introduction

Student engagement (SE) is a critical determinant of success in TVET, as it emphasises practical, competence-oriented learning essential for workforce readiness. However, maintaining high levels of engagement remains a persistent challenge in many TVET programmes. Disengaged students often struggle with diminished motivation, reduced interest in learning, and inadequate workforce skills, ultimately hindering their ability to meet the demands of an evolving labour market (Matalka et al., 2024). Studies have identified several contributing factors, such as teacher-centred instructional methods (Kim et al., 2025), insufficient practical facilities (Heikkinen et al., 2025), and a misalignment between curriculum content and industry needs (Squalli Houssaini et al., 2024). These issues affect students' competence and their ability to compete effectively in a rapidly evolving labour market.

Improving SE is a pathway to better learning outcomes and a strategic means to align TVET programmes with industry expectations. Engaged students actively participate in learning processes, fostering the acquisition of technical expertise, problem-solving abilities, and interpersonal skills. Research underscores that engagement enhances intrinsic motivation, cultivates a sense of responsibility for learning, and strengthens the connection between educational content and real-world applications (Dangeni, 2023; Niittylahti et al., 2023). This alignment creates a dynamic, interactive learning environment that equips students with technical and soft skills, fostering their preparedness for industry demands (Partsei et al., 2025).

Given the growing interest in addressing engagement in TVET, various approaches have been explored to foster SE. Recent studies highlight the effectiveness of innovative teaching methodologies, such as interactive technology (Chen et al., 2025), collaborative learning (Jain et al., 2024), and student-centred strategies (Rahimi, 2024). Among these, project-based learning (PjBL) has become a pragmatic approach for TVET. PjBL immerses students in real-life projects, enabling them to apply theoretical knowledge in practical contexts (Payoungkiattikun et al., 2025). This method nurtures critical skills, including problem-solving, teamwork, and adaptability—qualities essential for success in vocational careers. Furthermore, working on real-world problems fosters a stronger connection with the subject matter, increasing students' motivation and interest in learning (Ahmad et al., 2023; Shekhar et al., 2024).

Despite its advantages, implementing PjBL in online or blended learning environments presents unique challenges, particularly in TVET contexts that traditionally rely on hands-on training. The absence of physical interaction and practical sessions in purely online settings can reduce the effectiveness of PjBL in fostering engagement and collaboration. However, Mobile Learning (ML) offers a potential solution to these challenges. By leveraging mobile technologies, educators can create flexible, accessible, and interactive learning environments that facilitate collaborative and self-directed learning (Hameed et al., 2024; Muskhir et al., 2025). ML enables students to engage with course content, communicate with peers, and solve real-life problems, complementing the principles of PjBL (Fadli et al., 2024).

Given these gaps in research and the growing urgency for innovative pedagogical strategies in TVET settings, this study was designed to investigate the integrated impact of Project-Based Learning and Mobile Learning on student engagement. Specifically, it aims to address the following research questions: (1) To what extent does Project-Based Learning directly impact student engagement in cognitive, behavioural, and emotional dimensions? (2) How does Mobile Learning contribute to student engagement in vocational education? Moreover, (3) Does Mobile Learning mediate the relationship between Project-Based Learning and student engagement? These questions are designed to inform the development of a conceptual and empirical model that reflects contemporary learning realities and offers actionable insights for educators, curriculum designers, and policymakers. Through this inquiry, the study aims to advance a more holistic and future-oriented understanding of how technology and pedagogy can be integrated to foster meaningful learning experiences in TVET.

2. Literature Review

2.1 Student Engagement in TVET

Student engagement (SE) is a multidimensional construct that reflects how students actively participate in learning, invest cognitively and emotionally, and commit to mastering course content (Cui & Wang, 2024). In TVET, where practical competencies and problem-solving abilities are fundamental, fostering high levels of engagement is essential for producing workforce-ready graduates. Research consistently shows that greater engagement is associated with improved academic performance, positive attitudes toward learning, and the development of critical workplace skills (Hellín et al., 2023; Mvuyana & Ngcobo, 2024).

SE in TVET can be examined through three interrelated dimensions: cognitive, emotional, and behavioural engagement (Niittylahti et al., 2023). Cognitive engagement involves students' efforts to deeply understand course material and connect it to real-world applications, ensuring relevance to their professional goals. Emotional engagement highlights students' intrinsic motivation, enjoyment, and interest in learning activities. On the other hand, behavioural engagement reflects active participation, such as regular attendance, timely completion of assignments, and collaboration in group projects. Together, these dimensions equip TVET students with the technical and soft skills to meet the labour market demands (Rafiq et al., 2022).

Despite its importance, maintaining high levels of engagement in TVET remains a challenge. Traditional teacher-centred pedagogies often rely on rote learning, which fails to accommodate diverse student needs and leads to decreased motivation (Rahimi, 2024). Moreover, limited opportunities for practical, hands-on problem-solving can leave students feeling disconnected from the curriculum, leading them to perceive it as misaligned with their career aspirations (Wulansari et al., 2023). This disengagement is problematic, as research links high levels of engagement to enhanced technical skills, improved problem-solving capabilities, and increased perseverance in addressing challenges (Dangeni, 2023). Engaged students are more likely to achieve job-readiness, complete training programmes, and excel in industry-valued tasks (Matalka et al., 2024). Furthermore,

studies suggest that engagement is a key factor in improving retention rates, as motivated students are more likely to persist in their studies (Camilleri & Camilleri, 2023).

TVET institutions have increasingly adopted innovative pedagogical approaches to address these challenges, such as PjBL. PjBL emphasises real-world applications, collaborative problem-solving, and experiential learning tasks, which foster meaningful engagement by connecting academic objectives to professional requirements (Zhang & Watson, 2025). This approach represents a significant shift from passive, lecture-based instruction to active, student-centred learning, which has proven effective in TVET. PjBL enhances students' technical competencies and cultivates teamwork and adaptability—skills essential for thriving in fast-evolving industries.

However, while PjBL has shown considerable promise, integrating it effectively into TVET remains complex, particularly in online or blended learning contexts. ML offers a potential solution to this challenge by providing flexible and interactive platforms that support both independent and collaborative learning. ML enables students to engage with content anytime, anywhere, fostering sustained motivation and active participation. Combining PjBL with ML could create a synergistic effect, offering TVET programs a pathway to overcome barriers to engagement while equipping students with the skills required in the modern workforce. Further exploration of PjBL and ML integration is crucial for advancing SE in TVET. By leveraging innovative teaching methods and technology, educators can create dynamic, relevant, and engaging learning environments that align with industry demands and prepare students for the complexities of contemporary vocational careers.

2.2 Integration of Mobile Learning and Project-Based Learning in TVET

Integrating ML with PjBL represents an innovative approach to addressing engagement challenges in TVET. As TVET focuses on skill-based training and workplace preparation, it requires methodologies that engage students and align closely with industry demands. ML offers flexible, accessible platforms that enable students to interact with learning resources, collaborate with peers, and apply knowledge in real-world contexts. This flexibility fosters autonomy and intrinsic motivation, critical for sustaining engagement in dynamic educational environments (Ong & Quek, 2023). Concurrently, PjBL immerses students in meaningful, real-world projects, bridging theoretical concepts with practical applications while promoting collaborative and active learning (Ahmad et al., 2023). ML and PjBL create a synergistic framework that enhances cognitive, emotional, and behavioural engagement, all essential for vocational success (Benlaghrissi & Ouahidi, 2024).

PjBL is particularly effective in TVET because it emphasises constructive, independent, collaborative, and contextual learning (Cole, 2024). Constructive learning enables students to synthesise and apply information to solve real-life problems. In contrast, independent learning encourages them to take ownership of their educational journey, fostering accountability that mirrors professional expectations. Collaborative learning builds teamwork skills, aligns with industry practices, and prepares students for workplace dynamics. Lastly, contextual learning connects academic content with hands-on, industry-relevant scenarios, allowing students to recognise the applicability and value of their skills. These dimensions collectively make PjBL a powerful strategy for creating meaningful engagement and equipping students with the competencies needed for success in the labour market.

ML complements PjBL by providing a technology-driven platform that supports flexible and innovative learning processes. Indicators of effective ML implementation include familiarity, ease of use, and interface design (Hameed et al., 2024). Familiarity ensures students can seamlessly adopt mobile technologies, while ease of use and robust communication tools facilitate collaboration across diverse contexts. Additionally, well-designed interfaces enhance user experience, enabling students to access resources, complete tasks, and manage projects efficiently. For instance, mobile applications would allow students to document findings in real-world scenarios, participate in group assignments, and receive immediate feedback from instructors. These features make the learning process more engaging and interactive, reinforcing the principles of PjBL (Alarfaj et al., 2024).

Integrating ML and PjBL also addresses key psychological needs identified in Self-Determination Theory—autonomy, competence, and relatedness (Fadli et al., 2024). ML supports autonomy by enabling self-paced learning, allowing students to access resources and complete tasks at their own pace. Meanwhile, PjBL fosters competence through hands-on, constructive activities and strengthens relatedness by emphasising group collaboration and teamwork. Empirical evidence supports this integration, demonstrating significant improvements in vocational students' problem-solving abilities, collaboration, and perseverance when PjBL is combined with ML (Benlaghrissi & Ouahidi, 2024). Furthermore, ML enhances the accessibility and personalisation of PjBL, allowing students to tailor their learning experiences to align with career aspirations (Nikolopoulou, 2023). These findings highlight how integrating PjBL and ML aligns with TVET's objectives of equipping students with practical skills and industry readiness.

The ML application used in this study exemplifies this integration by providing an interactive, dynamic platform that enhances student engagement. It integrates theoretical knowledge with practical applications, fostering a comprehensive and immersive learning environment. As illustrated in Figure 1, the application features a user-friendly design, intuitive navigation, and tools specifically tailored to facilitate PjBL. These functionalities enable students to collaborate effectively, access educational resources on demand, and receive

timely feedback. By addressing cognitive, social, and behavioural dimensions of engagement, the application aligns with the study’s goal of advancing meaningful and practical learning experiences in TVET.

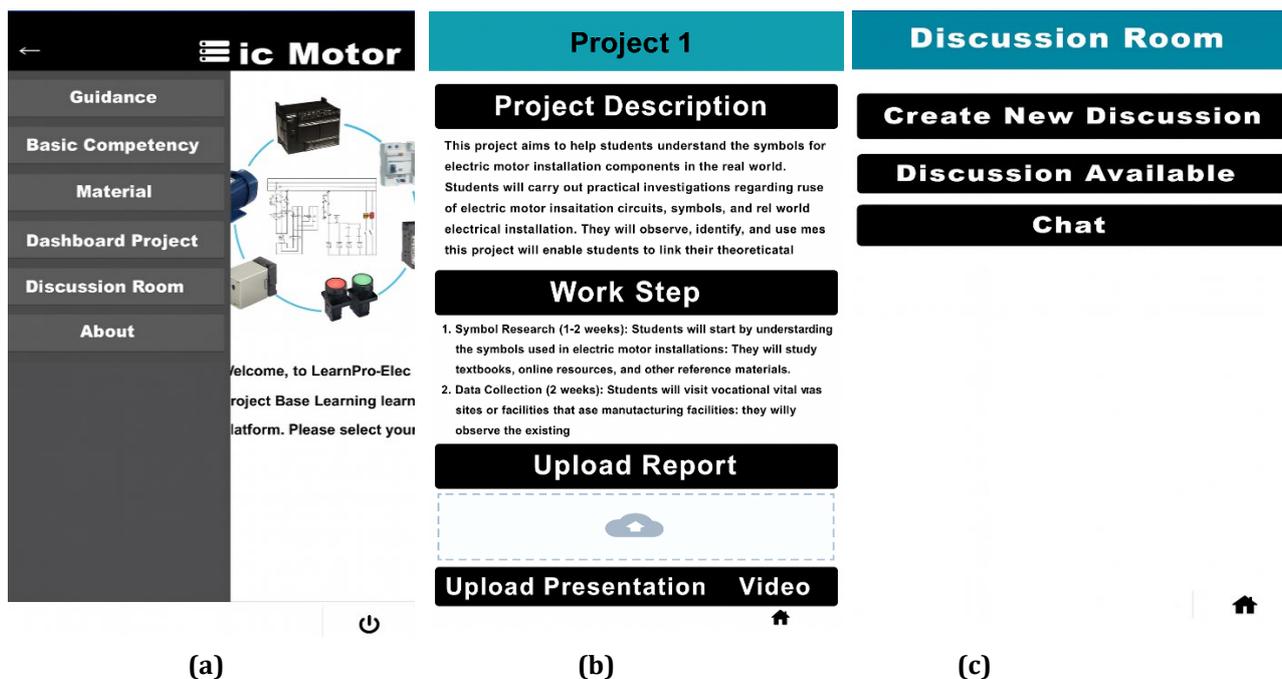


Fig. 1 (a) Main page; (b) Project dashboard; (c) Discussion room

3. Methodology

This study aims to analyse the impact of PjBL and ML on SE in TVET. A quantitative research approach was employed, utilising an explanatory causal design to investigate the cause-and-effect relationships among the variables. Specifically, this study investigates how PjBL and ML enhance SE across its cognitive, social, and behavioural dimensions in TVET. The study utilised Structural Equation Modelling (SEM) as the primary analytical technique to examine these relationships. SEM was chosen for its ability to analyse complex relationships among latent variables, which are constructs that cannot be directly observed. These latent variables—PjBL, ML, and SE—were operationalised using theoretically grounded indicators from the literature. SEM allows simultaneous analysis of these relationships, providing robust and comprehensive insights into the interplay between PjBL, ML, and SE.

3.1 Participants

This study involved 40 TVET students enrolled in the Electrical Motor Installation course at Universitas Negeri Padang. Participants were selected using a purposive sampling technique, considering their direct involvement in instructional sessions that combined Project-Based Learning (PjBL) and Mobile Learning (ML) strategies. The selection criteria were based on the relevance of the course content to the research intervention and on the participants’ prior exposure to both learning approaches. Although the number of participants may be considered relatively small in the context of quantitative research, it aligns with the methodological requirements of Partial Least Squares Structural Equation Modelling (PLS-SEM), the primary analytical method employed. According to Hair et al. (2020), PLS-SEM is particularly suited for exploratory studies and can produce valid and reliable results, even with small sample sizes, especially when the structural model is moderately complex and the indicators are well-constructed. A minimum of 30 to 50 participants is generally acceptable for models involving a limited number of latent variables and indicators. Unlike covariance-based SEM, PLS-SEM does not assume normality of the data. It effectively accommodates small sample sizes by utilising bias-corrected and accelerated (BCa) bootstrapping procedures, thereby ensuring reliable path coefficient estimation and statistical inference (Hair et al., 2019). In addition, the use of SmartPLS software further justifies this approach, as it accommodates smaller samples and non-normal data distributions, which are common in educational settings. The focused and intervention-specific nature of this study, which targeted a clearly defined group of vocational students, supports the appropriateness of the chosen sample. Therefore, the sample size of 40 is both methodologically sound and contextually justified for the aims of this study.

3.2 Variables and Indicators

The study assessed three primary constructs through well-defined dimensions and indicators, as shown in Table 1.

Table 1 *Variables and indicators framework*

Variables	Indicators/Dimensions	Explanation	Theoretical Framework
PjBL (X1)	Constructive Learning (X1.1)	Students actively construct knowledge by synthesising information and applying it to real-world problems.	(Cole, 2024; Turk & Berman, 2024)
	Independent Learning (X1.2)	Encourages students to take responsibility for their learning progress, fostering autonomy and accountability.	
	Collaborative Learning (X1.3)	Promotes teamwork, reflecting workplace dynamics, and prepares students for industry practices.	
	Contextual Learning (X1.4)	Connects academic content to industry-relevant, hands-on scenarios, enhancing the real-world applicability of skills.	
ML (X2)	Familiarity (X2.1)	Students' ability to quickly adapt and use mobile technologies for educational purposes.	(Hameed et al., 2024; Salhab & Daher, 2023)
	Ease of Use (X2.2)	Refers to the intuitive nature of mobile platforms, which enable seamless communication and learning.	
	Interface/Design (X2.3)	User-friendly design and navigation enhance the user experience, making learning more efficient and engaging.	
SE (Y)	Cognitive Engagement (Y1)	Reflects the depth of students' understanding, critical thinking, and the relevance of content to real-life applications.	(Heikkinen et al., 2025; Niittylahti et al., 2023)
	Social Engagement (Y2)	Represents students' collaboration and interactions with peers and instructors in learning activities.	
	Behavioural Engagement (Y3)	Involves active participation, such as attending classes, completing assignments, and engaging in group projects.	

These indicators were carefully chosen to form a robust framework that captures how PjBL and ML enhance SE by integrating practical, collaborative, and technology-mediated learning approaches. Figure 2 illustrates the conceptual framework guiding this research.

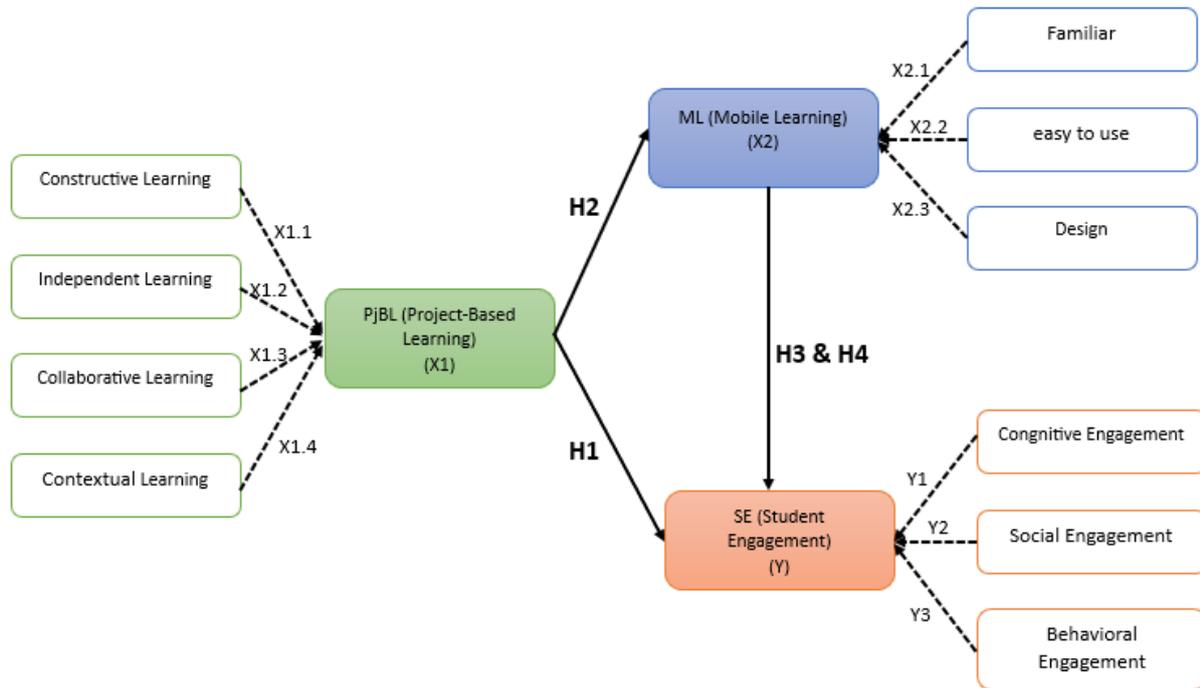


Fig. 2 The conceptual framework

3.3 Instruments Validity and Reliability

Data were gathered through a structured questionnaire to assess students' experiences with PjBL delivered via ML. The questionnaire consisted of closed-ended statements reflecting the identified indicators for each construct. Respondents were asked to rate their agreement on a 5-point Likert scale, ranging from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*). The questionnaire's validity and reliability were evaluated using SPSS 27.0 for Windows. Validity was assessed using the t-value; the instrument was considered valid if the calculated t-value was equal to or greater than the critical t-value ($t\text{-statistic} \geq t\text{-table}$). Similarly, reliability was evaluated to confirm the consistency of the measurement scale across different items. The following are the results of the validity and reliability testing of the instruments.

Table 2 Result validity test of PjBL instrument

No.Item	r statistic	r table	Result
1	0.492	0.312	Valid
2	0.490	0.312	Valid
3	0.527	0.312	Valid
4	0.518	0.312	Valid
5	0.541	0.312	Valid
6	0.522	0.312	Valid
7	0.512	0.312	Valid
8	0.488	0.312	Valid
9	0.507	0.312	Valid
10	0.504	0.312	Valid
11	0.591	0.312	Valid
12	0.550	0.312	Valid
13	0.534	0.312	Valid
14	0.526	0.312	Valid
15	0.552	0.312	Valid
16	0.521	0.312	Valid

The validity test results for the PjBL instrument items are presented in Table 2. The analysis indicates that all items fall into the "valid" category and are suitable for use in the research instrument. Similarly, the validity test results for the ML instrument items are presented in Table 3, indicating that all items are valid and suitable for inclusion in the study.

Table 3 Result validity test of ML instrument

No.Item	r statistic	r table	Result
1	0.714	0.312	Valid
2	0.570	0.312	Valid
3	0.623	0.312	Valid
4	0.562	0.312	Valid
5	0.495	0.312	Valid
6	0.539	0.312	Valid
7	0.472	0.312	Valid
8	0.730	0.312	Valid
9	0.693	0.312	Valid
10	0.517	0.312	Valid
11	0.555	0.312	Valid
12	0.537	0.312	Valid

Additionally, the results of the validity test for the SE instrument items are detailed in Table 4, confirming that all items meet the validity criteria and are valid for use in this research.

Table 4 Result validity test of SE instrument

No.Item	r statistic	r table	Result
1	0.545	0.312	Valid
2	0.620	0.312	Valid
3	0.734	0.312	Valid
4	0.606	0.312	Valid
5	0.531	0.312	Valid
6	0.528	0.312	Valid
7	0.602	0.312	Valid
8	0.535	0.312	Valid
9	0.627	0.312	Valid
10	0.606	0.312	Valid
11	0.607	0.312	Valid
12	0.530	0.312	Valid

Following the validity testing, a reliability test was conducted to assess the questionnaire's consistency. The Cronbach's Alpha coefficient was employed to evaluate the reliability of the instruments. As shown in Table 5, all items for each variable used in this study are reliable and demonstrate high internal consistency.

Table 5 Summary of reliability test of instrument

No	Variables	Cronbach's Alpha	Result
1	Project-Based Learning (PjBL)	0.823	Reliable
2	Mobile Learning (ML)	0.817	Reliable
3	Student Engagement (SE)	0.825	Reliable

3.4 Data Analysis

SEM was employed as the primary analytical method to assess the relationships among the constructs in this study: PjBL, ML, and SE. SEM was selected for its strength in evaluating complex relationships among latent variables, each measured by multiple indicators. Unlike traditional regression analysis, SEM allows for the simultaneous testing of both measurement models (which assess the reliability and validity of the observed indicators for each latent construct) and structural models (which test the hypothesised causal relationships among constructs).

This study employed SEM to investigate both the direct and indirect effects of PjBL and ML on SE, as well as the mediating role of ML between PjBL and SE. This dual focus makes SEM an appropriate tool, as it enables comprehensive modelling of observed and latent constructs while accounting for measurement error. The analysis proceeded in two stages: (1) outer model analysis, which validated the constructs by testing convergent validity, discriminant validity, and internal consistency reliability; and (2) inner model analysis, which tested the structural relationships among the constructs and evaluated the model's explanatory power.

While a sample size of 44 may appear modest, it meets the criteria for PLS-SEM, which is widely recognised for its robustness in exploratory research, particularly when working with small to medium samples (Hair et al., 2020). Unlike covariance-based SEM, PLS-SEM does not assume normality of the data. It effectively accommodates small sample sizes by utilising bias-corrected accelerated (BCa) bootstrapping, thereby ensuring reliable path coefficient estimation and statistical inference. Moreover, the diversity in gender and academic backgrounds strengthened the validity and representativeness of the findings. Model fit was assessed using standard indices such as SRMR, NFI, RMS Theta, and the Chi-square statistic, and the strength of path coefficients was interpreted using bootstrapping procedures. Through this analytical process, the study provides a statistically grounded explanation of how PjBL and ML interact to foster cognitive, emotional, and behavioural engagement in TVET learning environments.

4. Results

4.1 Research Model Analysis

This section presents the empirical findings derived from the structural model analysis among PjBL, ML, and SE. The study reveals the direct and indirect effects of PjBL on SE, as well as the mediating role of ML in these relationships. Additionally, it highlights the simultaneous influence of PjBL and ML on student engagement in TVET, showcasing their combined potential to enhance engagement. The SEM framework used for analysis is depicted in Figure 3.

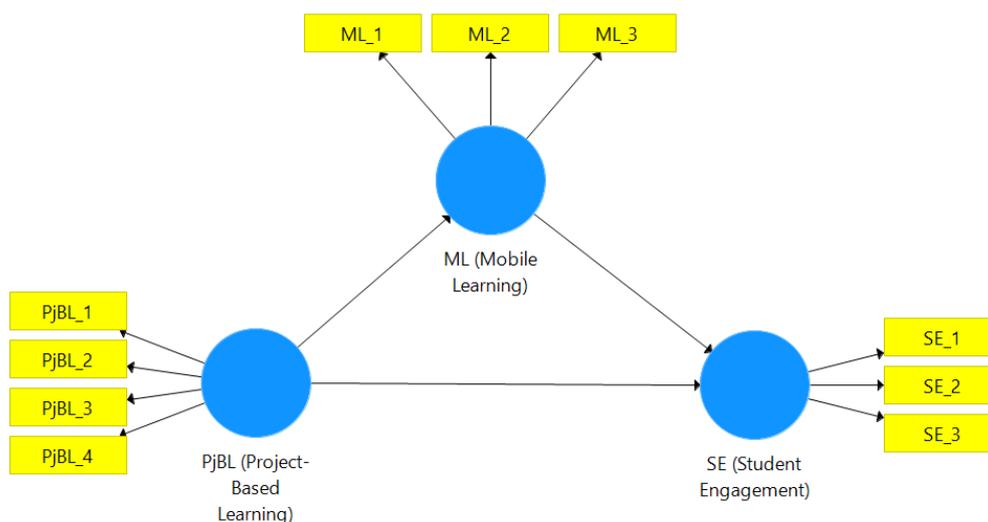


Fig. 3 Model of initial approach

The initial SEM model was evaluated to ensure compliance with its underlying assumptions and prerequisites. Two primary diagnostic tests—outer model analysis (for indicators) and inner model analysis (for latent variables)—were conducted to check for multicollinearity. As shown in Table 6, all outer VIF (Variance Inflation Factor) values fall below the conventional threshold of 5 ($VIF < 5$), indicating that the indicators do not exhibit problematic multicollinearity. This supports the stability and reliability of the individual items in representing their respective constructs.

Table 6 *Outer VIF values analysis*

No	Indicators	VIF
1	PjBL 1	1.795
2	PjBL 2	2.771
3	PjBL 3	2.378
4	PjBL 4	2.493
5	ML 1	1.627
6	ML 2	1.496
7	ML 3	1.620
8	SE 1	1.971
9	SE 2	2.760
10	SE 3	2.194

Further assessment was conducted at the latent variable level to verify the absence of multicollinearity in the inner model. Table 7 presents the inner VIF values for each latent construct, with all values remaining below 5, confirming that high intercorrelations do not distort the structural relationships among the variables. These results establish a strong foundation for continuing with the path analysis.

Table 7 *Inner VIF values analysis*

	PjBL	ML	SE
PjBL	-	1.000	2.477
ML	-	-	2.171

The model's overall goodness-of-fit (GoF) was assessed using criteria such as SRMR, NFI, RMS Theta, and Chi-square, as summarised in Table 8. The results validate the model's robustness, with all coefficients meeting or exceeding their respective thresholds, including an SRMR value of 0.062 (≤ 0.08) and an NFI value of 0.992 (≥ 0.9).

Table 8 *GoF analysis results*

GoF	Coefficient	Criteria	Result
SRMR	0.062	≤ 0.08	Fit
NFI	0.992	≥ 0.9	Fit
RMS Theta	0.073	≤ 0.1	Fit
Chi-Square	53.33	Small	Fit

Figure 6 visualises the full results of the structural model analysis, including path coefficients and significance levels. This serves as the basis for interpreting the effects among the constructs in the following sections.

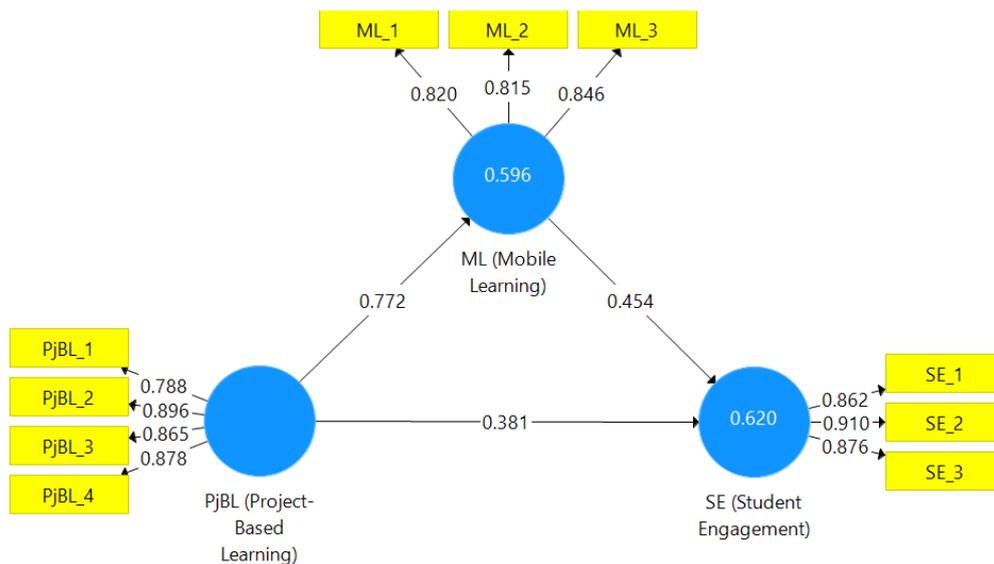


Fig. 4 Results of SEM analysis for the final approach

4.2 Indicator Analysis

The outer model analysis evaluated indicators and reliability using tests of convergent validity, construct reliability, discriminant validity, cross-loadings, and unidimensionality. Internal consistency reliability was assessed using Cronbach’s Alpha, with all variables exceeding the recommended threshold (> 0.7). Composite reliability values surpassed 0.7, and AVE values exceeded 0.5, confirming unidimensionality and convergent validity. These results, summarised in Table 9, verify that the measurement instruments are valid and reliable.

Table 9 Outer model analysis results

Variable	Cronbach’s Alpha	Rho_A	AVE	Unidimensionality	Convergent Validity
PjBL	0.770	0.774	0.684	Reliable	Valid
ML	0.879	0.885	0.736	Reliable	Valid
SE	0.858	0.858	0.780	Reliable	Valid

4.3 Structural Model Analysis

The structural model analysis reveals key findings regarding the direct and indirect effects among the variables, as shown in Table 10.

Table 10 Structural model analysis results

Test	Coefficients			t-value	Results
	Direct	Indirect	Total		
PjBL → SE	0.381	-	0.381	2.104	Significant
PjBL → ML	0.772	-	0.772	5.890	Significant
ML → SE	0.454	-	0.454	2.241	Significant
PjBL → ML → SE	-	0.351	0.351	2.047	Significant

The findings indicate that PjBL significantly influences SE, both directly (38.1%) and indirectly through ML (35.1%), highlighting its pivotal role in fostering engagement through active, contextual learning. Additionally, ML has a significant impact on SE, accounting for 45.4% of the effect, underscoring its importance as a flexible, interactive learning platform. The mediation analysis confirms that ML amplifies the impact of PjBL on SE, creating a synergistic relationship between innovative pedagogy and technology. These results underscore the potential of integrating PjBL and ML to enhance student engagement in TVET, providing valuable insights for educators, curriculum developers, and policymakers.

5. Discussion

This study offers significant insights into the transformative potential of integrating Project-Based Learning (PjBL) and Mobile Learning (ML) to enhance Student Engagement (SE) in TVET. By employing a Structural Equation Modelling (SEM) approach, the findings reveal the direct and indirect effects of PjBL on SE, as well as the mediating role of ML in this relationship. The direct impact of PjBL on SE, indicated by a coefficient value of 0.381, underscores its efficacy in fostering cognitive, behavioural, and emotional engagement. These findings are consistent with prior research that identifies PjBL as a powerful pedagogical approach for engaging students through authentic, collaborative problem-solving tasks. For instance, Alarfaj et al. (2024) emphasise that PjBL allows students to take ownership of their learning, thereby promoting intrinsic motivation—a critical factor in enhancing engagement. In TVET, which prioritises practical application and real-world relevance, PjBL is an effective bridge between theory and practice, providing students with opportunities to develop critical thinking and problem-solving skills in a hands-on environment (Hao et al., 2024). Moreover, aligning these findings with the Self-Determination Theory reinforces the role of PjBL in meeting the psychological needs of autonomy, competence, and relatedness (Chiu, 2024). By actively enabling students to participate in their learning process, PjBL fosters independence and competence, while collaborative project work enhances relatedness. These psychological factors collectively contribute to sustained student engagement, making PjBL a valuable strategy in educational settings (Ahmad et al., 2023).

The study also highlights the crucial role of ML as a mediator in the relationship between PjBL and SE. With PjBL directly affecting ML (0.772) and ML's subsequent impact on SE (0.454), the data suggest that ML amplifies the benefits of PjBL by providing flexible, interactive, and accessible learning environments. This finding aligns with existing literature, such as Batubara et al. (2023), which highlights the potential of ML to support personalised and anytime-anywhere learning. In the context of TVET, ML extends the reach of PjBL by enabling students to document practical tasks, access digital resources, and collaborate with peers on real-world projects. These activities enhance cognitive engagement and promote behavioural and social interactions, as emphasised by mobile learning frameworks (Moya & Camacho, 2024). For example, mobile applications can facilitate real-time feedback, allowing students to refine their understanding and skills in a dynamic learning environment. This synergy between PjBL and ML is particularly significant in TVET, where students benefit from hands-on and contextual learning experiences enhanced by technological tools (Karatay et al., 2024).

The indirect effect of PjBL on SE via ML, with a coefficient of 0.351, underscores the complementary nature of these approaches. This synergy is crucial for addressing the multidimensional nature of student engagement, encompassing cognitive, behavioural, and emotional dimensions. By integrating PjBL and ML, educators can create a holistic learning environment that leverages the strengths of both pedagogical innovation and technological integration. For instance, using ML in PjBL projects can enhance collaboration by providing resource-sharing and communication platforms. This integration also supports the development of 21st-century skills, such as digital literacy and teamwork, which are essential for success in today's technology-driven world (Camilleri & Camilleri, 2023). Furthermore, the flexibility offered by ML enables students to engage with learning materials at their own pace, thereby accommodating diverse learning needs and preferences. These findings highlight the potential of combining PjBL and ML to design impactful and meaningful educational experiences that prepare students for the complexities of the modern workforce (Anuyahong & Pucharoen, 2023).

The reliability of the indicators used in this study further strengthens the validity of the findings. The high reliability of PjBL indicators (ranging from 0.788 to 0.896) confirms its consistency in fostering engagement. Similarly, the reliability of ML indicators (0.815-0.846) demonstrates the effectiveness of mobile technologies in supporting learning processes. Lastly, the strong reliability of SE indicators (0.862-0.910) highlights the comprehensive approach to measuring engagement's cognitive, behavioural, and emotional aspects. These results are consistent with prior studies emphasising the multidimensional nature of student engagement (Sureda-García et al., 2021). Additionally, the alignment with Self-Determination Theory reinforces the theoretical foundation of this study, demonstrating how the integration of PjBL and ML addresses key psychological needs that drive engagement (Oanh & Dang, 2025). By combining these approaches, educators can create a learning environment that meets academic objectives and supports students' holistic development.

The implications of this study are particularly significant for TVET, where preparing students with practical skills and competencies is a primary goal. Educators are encouraged to adopt PjBL and ML strategies to create interactive and relevant learning experiences that align with the demands of the modern workforce. For example, integrating ML tools into PjBL projects can enhance students' ability to apply theoretical knowledge in real-world contexts, improving their readiness for professional challenges (Badir et al., 2023). Institutions must also invest in technological infrastructure and provide professional development opportunities for educators to implement these strategies effectively. Training programmes should focus on equipping teachers with the skills needed to design and facilitate PjBL projects that leverage ML tools. Additionally, policymakers should recognise the value of these integrated approaches and support their adoption through funding and policy initiatives. By prioritising

the integration of PjBL and ML, TVET can address the evolving needs of students and employers in a rapidly changing technological landscape (Gomes et al., 2025).

In addition to its practical implications, this study enriches the theoretical understanding of how PjBL and ML interplay to influence SE. The findings contribute to the growing literature on educational technology and pedagogy by demonstrating the synergistic effects of combining these approaches. By addressing the cognitive, behavioural, and social dimensions of engagement, this study provides a comprehensive framework for understanding how pedagogical and technological innovations can be integrated to enhance learning outcomes. Moreover, aligning with the Self-Determination Theory underscores the importance of meeting students' psychological needs to foster engagement (Gagnon et al., 2024). By enabling autonomy, competence, and relatedness, the integration of PjBL and ML creates a supportive learning environment that promotes intrinsic motivation and sustained engagement. This theoretical contribution highlights the potential of combining pedagogical and technological approaches to design impactful educational experiences that address the complexities of a technology-driven world (Rahimi, 2024).

The findings of this study are particularly relevant in the context of global trends and post-pandemic education. The COVID-19 pandemic has accelerated the adoption of digital technologies in education, highlighting the need for flexible and interactive learning solutions (Ng & Lo, 2023). The integration of PjBL and ML aligns with these trends, providing a robust framework for addressing the challenges and opportunities of post-pandemic education. For instance, the flexibility offered by ML can support remote and hybrid learning models, ensuring that students can continue to engage with their education regardless of location. Similarly, PjBL's emphasis on real-world problem-solving aligns with the demands of a rapidly changing workforce, where adaptability and critical thinking are essential skills (Hao et al., 2024). By integrating these approaches, educators can create resilient, future-ready learning environments that prepare students for success in a dynamic, uncertain world.

This study demonstrates the transformative potential of integrating PjBL and ML to enhance SE in TVET. By leveraging the strengths of both approaches, educators can create holistic learning environments that address the cognitive, behavioural, and emotional dimensions of engagement. The findings underscore the importance of aligning pedagogical innovation with technological advancements to design meaningful and relevant educational experiences. As TVET continues to evolve in response to global trends and technological advancements, integrating PjBL and ML offers a promising pathway to foster engagement and prepare students for the complexities of the modern workforce.

6. Conclusion

This study highlights the transformative potential of integrating Project-Based Learning (PjBL) with Mobile Learning (ML) to enhance Student Engagement (SE) in TVET. PjBL fosters constructive, independent, collaborative, and contextual learning, while ML provides the flexibility and interactivity needed to amplify these benefits. They create a framework that addresses cognitive, behavioural, and social engagement dimensions. Structural Equation Modelling (SEM) results confirm the direct impact of PjBL and ML on SE and the mediating role of ML in strengthening this relationship, underscoring their combined effectiveness in meeting the demands of modern vocational education. By aligning educational practices with industry needs, the integration of PjBL and ML prepares students with the competencies and adaptability required in today's workforce. This synergy provides a robust solution to educational challenges, making learning more interactive and relevant. Educators, institutions, and policymakers must collaborate to maximise the benefits of this integration. Educators should leverage these methods to design dynamic learning experiences while institutions invest in infrastructure and training. Policymakers should support this integration with resources and policies that encourage innovation. Together, these efforts can position TVET as a leader in equipping students for lifelong learning and success in a technology-driven global landscape.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** J.S.; **data collection:** J.S., D., O.C.; **analysis and interpretation:** J.S., D.F.Y., H.; **draft manuscript preparation:** J.S., D., O.C.; **writing—review and editing:** J.S., D.F.Y., H.; **supervision:** J.S., D. All authors reviewed and approved the final version of the manuscript.*

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