

Critical factors shaping project-based learning in mathematics education

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ABSTRACT

A total of 488 observations from secondary and high school teachers were randomly divided into two groups for conducting analysis: 244 for exploratory factor analysis (EFA) and 244 for confirmatory factor analysis (CFA). The experimental results from EFA revealed six latent factors, accumulating for over 68.43% of the variance in the data. The CFA reports validated the 6-factor model, demonstrating strong model fit indices and ensuring high reliability and validity. These factors discovered and named in this study are as: facilities and teaching support, capacity to organize project-based learning (PjBL), perception of PjBL, readiness for PjBL, teachers' confidence in applying PjBL, and students' characteristics. The findings validated these latent factors' model as a comprehensive framework for understanding the essential aspects of organizing PjBL. By addressing both the identification and empirical validation of influencing factors, the study thoroughly responds to the research questions and strengthens the overall contribution to the field. This study is novel in its development and validation of a context-specific measurement model for PjBL in mathematics education, particularly within the Vietnamese educational context, where empirically grounded models of this nature remain scarce. Furthermore, it offers valuable practical information for teachers, educational administrators, and researchers to enhance and promote the effective application of PjBL in mathematics education.

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1. INTRODUCTION

Mastering essential skills plays a critical role to success in this fast-changing world, and these abilities were acquired to trials and errors. In this regard, project-based learning (PjBL) is considered as preferable option among others. PjBL is believed to deepen students' understanding of academic content and enhances key 21st-century skills, including "...critical thinking, creativity, collaboration, and communication" [1], [2]. In the context of Vietnam, PjBL is gaining popular as an instructional method due to the educational reform policy in science, technology, engineering, and mathematics (STEM). Being considered as a core discipline in STEM, mathematics gains its in disponible position in the socio-economic development of every country [3], [4], because of its strong emphasis on logical thinking and reasoning. Thus, this subject is well-suited for PjBL [1], [4]. Yet, when applying to the real-world context, the PjBL implementation in mathematics encountered several challenges, such as teacher competency, students'

characteristics, school policies, infrastructure, and technological support [1], [2]. As such, there is a need to examine the factors influencing the organization of PjBL in mathematics to optimize its effectiveness.

There are several studies that explored and highlighted the benefits of PjBL in mathematics in the educational settings. For example, several studies [5], [6] demonstrated how mathematical concepts was achieved by implementing STEM-integrated PjBL model. In addition, PjBL was also shown to have a positive impact on students' attitudes toward technology and science, thus fostering greater interest and motivation in learning [2], [7]. In the same vein, another studies [8], [9] confirmed the effectiveness of the PjBL model in: i) increasing academic outcomes and conceptual understanding; ii) motivating learning; and iii) fostering higher-order thinking skills. Additionally, numerous studies emphasize the crucial role of teachers in designing, guiding, and assessing learning projects to ensure the successful implementation of PjBL [10], [11]. In Vietnam, several researchers explored the feasibility of PjBL in mathematics; however, these prior researches did not provide a comprehensive analysis of the factors influencing its application within the context of Vietnamese general education [12]–[14]. Furthermore, these research did not yet fully investigated the particular difficulties that educators and learners encounter when adopting PjBL in mathematics.

Despite extensive research on PjBL to date, numerous research gaps remain that require additional investigation. Research has yet to conduct a complete study of the elements shaping PjBL structure in mathematics while missing thorough evaluations of how regulations and technological supports impact this approach. Existing studies identified multiple challenges teachers experience when they design, implement, and evaluate mathematical projects during instructional practice. This study seeks to enhance current understanding by examining which factors affect the implementation of PjBL within secondary and high schools mathematics education. The research questions represent the specific focus of this study:

- i) What are the potential factors influencing the implementation of PjBL? (RQ1)
- ii) Are these factors sufficiently reliable and validated for use in further research? (RQ2)

This research gathers empirical data by surveying mathematics teachers from secondary and high school to improve PjBL application in mathematics teaching and suggests supportive strategies for educational institutions and policymakers.

The literature review will organize existing research about factors affecting PjBL implementation in secondary school mathematics through evaluation and synthesis of previous studies while pinpointing research gaps needing further investigation. The study will then describe the methods used for gathering and analyzing data. The research findings will identify the main factors impacting PjBL in mathematics before comparing these results with existing studies. The conclusion will bring together the primary discoveries and recognize study limitations before providing guidance for stakeholders to better implement PjBL methods in mathematics teaching.

2. LITERATURE REVIEW

This section provides an overview of key concepts, synthesizes and analyzes previous studies on PjBL in mathematics, categorizes research directions, and identifies gaps for the current study. PjBL is a contemporary teaching methodology wherein students proactively take part in exploring, researching, and solving real-world problems through project-based exercises [15]. This approach equips students with knowledge accumulation and enhances important skills, namely communicative skills, collaborative skills, creative and critical thinking skills [1], [2], [16]. In math education, PjBL has gained attention of researchers due to its ability to reinforce students' acquisition of mathematical concepts through real-world interactions [5], [6]. However, the implementation of this approach still encountered many facets, for example: teacher capacity, student engagement, school policies, infrastructure, and technology support [1], [10].

Project is a series of tasks that require students to be involved in a set of activities such as design, problem-solving, decision-making. PjBL purports at providing students a number of opportunities to work independently over a long duration and culminate in a product [15]. As such, PjBL is considered as a dynamic, student-centered learning model in which learners, set goals, collaborate, communicate, and reflect while solving real-world problems under the guidance of a teacher [1]. Stemmed from the "learning by doing" idea, PjBL focuses on achieving learning outcomes through active engagement in goal-oriented tasks. In addition, it also fosters critical thinking and promotes direct, hands-on participation, making learning more effective compared to conventional knowledge-based approaches [9].

In Vietnam, the Ministry of Education and Training reformed the new general education curriculum in 2018, which emphasizes competency-based learning and comprehensive student development. This curriculum requires significant changes in teaching methods to achieve lesson objectives while promoting student development. Accordingly, teachers are no longer simply knowledge providers but instead play the role of facilitators, guiding students to acquire knowledge and master essential skills [17]. Currently, many innovative teaching methods are widely applied in educational institutions, of which PjBL is one of the

most prominent methods [18]. This is explained by the fact that this approach is consistent with the student-centered orientation of the new general education program. Overall, studies on PjBL in mathematics education can be categorized into three primary groups.

The first group focuses on the effectiveness of PjBL when applied to specific environments. Overall, empirical results reported that the PjBL model has a positive impact on learning outcomes. For instance, Yunita *et al.* [6] found that the application of the PjBL model significantly improved students' understanding of mathematical concepts, problem-solving ability, creative thinking, critical thinking, and mathematical communication skills. Similarly, Asmi *et al.* [9] supplemented that PjBL improves academic achievement, higher-order thinking skills, learning motivation. Additionally, research by Ubuz and Aydinler [7] confirmed that students' knowledge and their attitudes towards the geometry showed different levels of improvement in PjBL environments, depending on their cognitive styles.

The second group examined individual factors that influence the implementation and effectiveness of PjBL. As an example, Kim [19] indicated that PjBL outcomes are shaped by students' interaction styles and their level of learning motivation, while research by Yunita *et al.* [6] dictated that mathematical ability is related to the process of PjBL. In another study, Viro *et al.* [2] revealed that teacher motivation is considered very important for the success of PjBL implementation. As a consequence, the outcomes of PjBL are influenced by several components, including how the curriculum is adapted, the level of teacher support and training, assessment practices, and the readiness of both educators and learners [8].

The third group explored the integration of PjBL with other teaching models and methods to enhance effectiveness. One approach is to propose hybrid teaching models that combine PjBL with complementary approaches to optimize learning outcomes. For instance, Zhang and Ma [20] recommended integrating PjBL with STEM education to foster students' positive attitudes toward STEM fields and encourage future career choices in these areas. In the same vein, research by Surmilasari *et al.* [21] showed that a STEM-based PjBL model would enhance students' creative thinking in mathematics learning. Furthermore, experimental studies examined the combination of PjBL with digital technology to improve student performance, such as using educational software to develop learning tools [22], [23]. Additionally, Supriadi *et al.* [24] highlighted that integrating PjBL with guided discovery learning is considered as an effective approach to strengthening students' mathematical abilities.

Although prior work demonstrated the benefits of PjBL, perspectives on its effectiveness in mathematics education remain varied. Research on the impact of PjBL confirmed that its application enhances students' mathematical abilities and increases their engagement in learning. Meanwhile, studies examining the factors influencing PjBL implementation highlighted enabling as well as limiting factors, such as teacher readiness, student participation, and institutional support. Additionally, research focused on improving PjBL explored ways to address its limitations by integrating it with other teaching methods or leveraging technology. However, a common finding across most studies is that PjBL requires careful preparation by teachers and strong institutional support to maximize its effectiveness. Based on previous studies, PjBL has shown great potential as an instructional method but has yet to be widely implemented in mathematics education due to various challenges. While existing publications provided substantial evidence of the benefits of PjBL, they also highlighted difficulties in practical application, particularly in general education settings. Key areas requiring further investigation include clearly identifying the factors influencing the implementation of PjBL in mathematics, especially within the context of Vietnamese education; examining the impact of PjBL on students' cognitive development and learning outcomes through empirical studies; and exploring hybrid models that integrate PjBL with other teaching methods to enhance its effectiveness. This study seeks to enhance the field by examining the factors influencing the application of PjBL in mathematics, with the goal of providing practical recommendations to boost its effectiveness in general education.

3. METHOD

3.1. Research design

This research adopts a quantitative methodology to investigate and analyze the factors influencing the implementation of PjBL in mathematics. Specifically, exploratory factor analysis (EFA) is utilized to identify latent variables within the collected data. EFA is commonly applied to uncover the underlying structure of a dataset, allowing for the reduction of observed variables into a more manageable set while retaining the most critical information [25]. As a dimensionality reduction technique, EFA helps identify key factor groups that impact the organization of PjBL. Following the extraction of factors through EFA, the study proceeds with confirmatory factor analysis (CFA) to validate the proposed model. The study used CFA to test the compatibility between the conceptual model and the collected data, validating the connections between underlying constructs and measurable indicators [25]. To ensure the reliability of the analysis, the collected data was randomly divided into two groups. The first group was used for EFA to

explore and identify key factors within the research model, while the second group was employed for CFA to validate and confirm the structure of the measurement model, ensuring its reliability and validity. The chosen methodology increases the study's rigor and trustworthiness, supporting a deeper understanding of the elements influencing PjBL in mathematics education.

3.2. Sample and data collection

This study focused on secondary and high school mathematics teachers to examine the factors influencing the implementation of PjBL. The research participants included mathematics teachers from the Northern, Central, and Southern regions of Vietnam. To ensure representativeness and alignment with the research objectives, the study employed a purposive sampling method, facilitating the recruitment of individuals who met the predetermined research criteria. To facilitate participation and ensure accessibility, data were gathered using a Google Forms-based online survey. Before the survey was administered, participants were thoroughly informed about the study's objectives, the type of data to be collected, how the data would be stored and used, and their right to participate voluntarily or withdraw at any point. The survey took place over a 3-month period, from January to March 2025.

The survey consisted of two main parts. The first section collected background information about participants, including their professional qualifications, teaching experience, and work environment. The second section consisted of 25 questions designed to assess teachers' perceptions of their readiness to implement PjBL in mathematics. A 5-point Likert scale was used to design the questions, with response options ranging from 1 (completely disagree) to 5 (completely agree). Drawing on previous studies on influencing factors identified by researchers worldwide, this study proposed five key factors, represented by 25 statements: teachers' project-based teaching skills, teachers' attitudes, students' characteristics, education policies, and facilities. The selection of these factors aimed to ensure a comprehensive insight into the circumstances impacting the success of PjBL in mathematics education. Table 1 outlines the survey items and their associated sources categorized by construct group.

Table 1. Survey questionnaire

Factor	Questionnaire	References
Teachers' PjBL skills	Q1. I understand how to integrate mathematics content into practical and interdisciplinary projects.	[1]–[3], [10]
	Q2. I recognize the process of PjBL, including planning, implementation, and evaluation.	
	Q3. I recognize that PjBL is more effective than traditional methods.	
	Q4. I can approach PjBL in a variety of ways.	
	Q5. I am able to plan, organize, and coordinate student groups.	
Teacher's attitude	Q6. I am able to design criteria, tools, and assessments for the process and products of PjBL.	[2], [10], [26], [27]
	Q7. I believe that PjBL is an effective method for enhancing student learning outcomes.	
	Q8. I am enthusiastic about implementing mathematical projects in the classroom.	
	Q9. I feel prepared to apply PjBL.	
	Q10. I believe that implementing PjBL helps students develop essential 21st-century skills such as critical thinking, communication, and collaboration.	
Students' characteristics	Q11. I am confident in designing and organizing PjBL activities.	[1], [3], [10], [20]
	Q12. Students with a strong understanding of mathematical concepts perform well in mathematical projects.	
	Q13. Students with good communication and collaboration skills excel in mathematical projects.	
	Q14. Students are confident and willing to work in groups when engaging in mathematical projects.	
	Q15. Most students remain focused while working on mathematical projects.	
Education policy	Q16. Students are enthusiastic and proactive in participating in mathematical projects to enhance their academic performance.	[1]–[3], [26], [27]
	Q17. I receive policies and guidelines from the school and government that effectively support the implementation of PjBL.	
	Q18. Policies and guidelines on PjBL are clear, easy to understand, and straightforward to implement.	
	Q19. Salary, bonuses, and material incentives influence the implementation of PjBL.	
	Q20. Regular seminars and training sessions help teachers update and enhance their skills in implementing PjBL.	
Facilities	Q21. I am provided with sufficient equipment, tools, and applications for project-based teaching.	[1], [3]
	Q22. The equipment, tools, and applications are in good working condition.	
	Q23. I can receive assistance from the service provider if I encounter issues with the equipment, tools, or applications.	
	Q24. The learning space is well-designed to support group work and the implementation of mathematical projects.	
	Q25. Learning materials are regularly updated to reflect innovations in teaching methods and technology.	

To verify that the survey tool was both reliable and valid, the questionnaire was reviewed by 2 experts in mathematics education before being widely administered. The collected data were thoroughly checked and processed, with incomplete responses removed using the listwise deletion method to maintain

the quality of statistical analysis. After 3 months of survey implementation, a total of 516 responses were collected. Of these, 28 responses (5.4%) were excluded due to missing data, leaving 488 valid responses (94.6%) for analysis. The data were then evenly divided into two groups: 244 responses for EFA and 244 responses for CFA.

Figure 1 illustrates the geographical distribution, showing that the majority of participants were from Nghe An (42.24%), followed by Thanh Hoa (12.79%), Hanoi (9.3%), Ha Tinh (8.72%), and Son La (4.84%), with the remaining participants spread across other regions. Regarding teaching experience, Figure 2 shows that the largest proportion of respondents (38%) had 10 years or less of teaching experience, followed by those with 21–30 years (36%) and 11–20 years (29%) of experience. The smallest percentage of participants (1%) were teachers with over 30 years of experience.

Area of Living	Count
Nghe An	218
Thanh Hoa	66
Ha Tinh	45
Son La	25
Dong Nai	22
Ha Noi	48
Ba Ria - Vung Tau	1
Bac Giang	1
Bac Ninh	3
Ben Tre	2
Binh Phuoc	3
Con Tho	1
Cao Bang	1
Da Nang	2
Dak Lak	18
Lam Dong	5
Gia Lai	5
Kon Tum	5
Lang Son	2
Long An	3
Nam Dinh	2
Ninh Binh	3
Phu Tho	5
Quang Ninh	3
Quang Tri	1
Thai Binh	3
Thai Nguyen	1
Hoa Binh	1
Ho Chi Minh city	15
Vinh Phuc	1
Yen Bai	5



Figure 1. Distribution of participants by geographic region

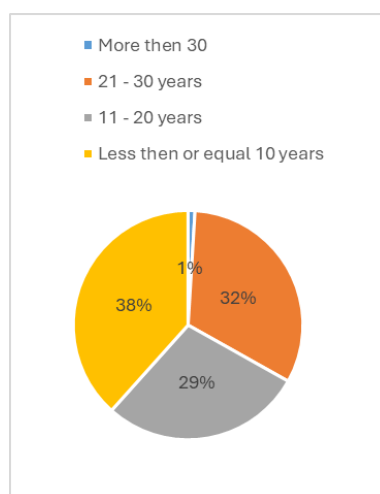


Figure 2. Distribution of participants by years of experience

3.3. Data analysis

EFA was conducted in the initial stage to identify latent structures or factors within the dataset. Analyzing individual correlations among the 25 observed variables can be complex and time-consuming, as it involves evaluating up to 300 correlation coefficients. EFA helps address this challenge by reducing the dimensionality of the data while clarifying the factor structure, providing researchers with a more comprehensive understanding of mathematics teachers' perceptions of PjBL. Additionally, if observed variables can be grouped into a smaller set of aggregate factors, other multivariate analysis methods can be applied more effectively. During the analysis, four observed variables (Q18, Q19, Q20, and Q25) were removed due to high cross-loadings (≥ 0.3) to ensure a clear and interpretable factor structure. As a result, 21 remaining variables were used for subsequent analyses. This study utilized 244 observations with 21 variables, yielding an observation-to-variable ratio of 11.6:1. According to Hair *et al.* [25], a ratio of 5:1 is considered acceptable, 10:1 is average, and 20:1 is excellent. Additionally, Bujang *et al.* [28] suggests that sample sizes can be determined based on specific thresholds such as 50, 100, 500, or over 1000 observations, depending on the research requirements. In this study, the 11.6:1 ratio exceeds the 10:1 benchmark, ensuring that the sample size meets the standard requirements for EFA factor analysis.

The EFA method assumes a correlation between observed variables; therefore, it is essential to assess the degree of correlation before conducting the analysis. In this study, two important statistical indices were applied to examine the appropriateness of the data for EFA. One of the primary indices is the Kaiser-Meyer-Olkin (KMO) coefficient, which measures the adequacy of the sample for factor analysis. A KMO value close to 1.0 indicates high suitability, whereas a value below 0.5 suggests that the data does not meet the necessary conditions for EFA [25], [29]. The second index used is Bartlett's test of sphericity, which assesses whether there is a significant correlation between observed variables. This test examines the hypothesis that the correlation matrix is an identity matrix (i.e., there are no significant relationships between variables). If the p-value (sig.) < 0.05 . The test results demonstrate that the correlations among variables meet the required threshold, thus justifying the use of EFA on the dataset [25].

The obtained data were processed using IBM SPSS version 25.0. In the factor analysis, the principal component analysis (PCA) method was employed to extract factors, combined with the Varimax rotation technique to optimize the factor structure and enhance interpretability. In this study, the authors did not predefine a fixed number of factors to be retained. However, with 21 observed variables, ensuring that each factor includes at least 2 representative variables (preferably 3 variables) was a key criterion in the factor analysis. Based on the recommendations of Hair *et al.* [25], the expected number of factors was estimated to be between 4 and 6.

To determine the optimal number of factors, the study applied common statistical criteria, including the Kaiser criterion (retaining only factors with eigenvalues greater than 1), the scree plot (identifying the number of factors based on the break point of the eigenvalue curve), and the explained variance ratio (confirming that the chosen factors explain most of the variance within the dataset). These criteria help ensure that the extracted factors are statistically significant and accurately represent the latent structure of the dataset. After completing EFA, CFA was subsequently performed to test the reliability and validity of the factors identified through EFA. The reliability of the measurement model was evaluated using composite reliability (CR) and average variance extracted (AVE). In accordance with established criteria, CR values exceeding 0.7 and AVE values above 0.5 indicate satisfactory convergent validity.

During the model evaluation process, the study applied multiple goodness-of-fit measures to assess the compatibility between the measurement model and the experimental data. Key measures included the chi-squared index divided by the degrees of freedom (CMIN/DF), which assesses how well the model fits the data as a whole. Additionally, the study utilized the goodness-of-fit index (GFI) and the adjusted goodness-of-fit index (AGFI) to measure the degree of fit between the proposed model and the observed data. The normed fit index (NFI) and comparative fit index (CFI) were utilized to evaluate improvements in model fit relative to a baseline model. Additionally, the root mean square error of approximation (RMSEA) and PCLOSE were calculated to assess the model's fit to the data, offering further evidence in support of the model's validity.

The criteria for evaluating the model's fit to the data were determined based on several statistical indices. CMIN/DF is considered a good fit if ≤ 3 and acceptable if ≤ 5 . GFI, AGFI, NFI, and CFI indicate a good fit when ≥ 0.9 , while values ≥ 0.95 are considered excellent fit [30]. RMSEA values are interpreted: < 0.01 represents excellent fit, < 0.05 indicates good fit, and < 0.08 suggests fair fit. Finally, the PCLOSE index is considered excellent if ≥ 0.05 , while ≥ 0.01 reflects an acceptable fit [25]. CFA was implemented in this research with the use of IBM Amos version 20.0, which enables precise and reliable testing of the measurement model structure.

4. RESULTS AND DISCUSSION

4.1. Results

4.1.1. Descriptive statistic

After filtering out noisy data, EFA was conducted on 21 questions using the Varimax rotation method. The analysis results from SPSS software provided the characteristic values for each factor. However, during data processing, the observed variables Q18, Q19, Q20, and Q25 exhibited cross-loading coefficients ≥ 0.3 across multiple factors. Consequently, the research team decided to remove these four variables and reanalyze the adjusted dataset. The mean and standard deviation, along with other descriptive statistics, are displayed in Table 2. The descriptive statistics table indicate that the mean values of the observed variables range from 3.03 to 3.84, suggesting a relatively high level of agreement among participants regarding the survey questions. The standard deviation ranges from 0.57 to 0.85, reflecting a moderate level of dispersion, with no variable displaying excessive variability. Additionally, skewness and kurtosis values are close to 0, indicating that the data distribution is neither highly skewed nor excessively peaked. This suggests that the dataset closely approximates a normal distribution, making it suitable for further statistical analyses such as EFA and CFA.

The results of the KMO and Bartlett's tests in this study confirmed the suitability of the dataset for factor analysis. The KMO index reached an acceptable level (0.724), as seen in Table 3, demonstrating that the sample size was suitable for EFA. Moreover, Bartlett's test of sphericity yielded a statistically significant result, confirming the appropriateness of the data for factor analysis. with $\chi^2(210)=1877.522$, $p<0.000$, demonstrating that the observed variables had a sufficiently strong correlation to justify the application of factor analysis.

Table 2. Mean, standard deviation, skewness, and kurtosis of observed variables

Variable	Mean	Std. Deviation	Skewness	Kurtosis
Q1	3.7295	0.75399	-0.088	0.255
Q2	3.3811	0.74135	-0.012	-0.003
Q3	3.5574	0.81194	-0.233	-0.194
Q4	3.2787	0.57036	0.193	-0.085
Q5	3.5574	0.68553	0.216	0.174
Q6	3.0287	0.66913	-0.033	0.766
Q7	3.4098	0.77782	-0.067	-0.164
Q8	3.4385	0.82172	0.109	-0.27
Q9	3.5574	0.85152	-0.06	-0.6
Q10	3.4918	0.7617	-0.085	-0.044
Q11	3.5656	0.81132	-0.261	-0.176
Q12	3.4713	0.71088	0.067	-0.224
Q13	3.5902	0.79353	-0.125	0.369
Q14	3.6885	0.77068	-0.161	-0.029
Q15	3.4795	0.80864	0.09	-0.228
Q16	3.1352	0.81785	0.246	-0.1
Q17	3.2008	0.75129	0.004	0.367
Q21	3.8402	0.65031	-0.011	-0.287
Q22	3.3156	0.80303	-0.152	0.015
Q23	3.5123	0.72283	-0.208	0.131
Q24	3.6066	0.76505	-0.253	-0.241

Table 3. KMO and Bartlett's test

Test	Value
KMO measure of sampling adequacy	0.724
Bartlett's test of sphericity	Approx. Chi-square 1877.522
	Df 210
	Sig. 0.000

4.1.2. Exploratory factor analysis

To answer the first research question, this section reports the outcomes of the EFA to identify the latent factors that influence the organization of PjBL in mathematics teaching. In Table 4, the extracted factors are displayed alongside their eigenvalues, explained variances, and cumulative variances. Following the Kaiser criterion, only factors with eigenvalues greater than 1 were retained in the model. The analysis results from 21 observed variables identified six factors influencing the organization of PjBL, which is one factor more than initially expected.

The total variance explained by the six extracted factors reached 68.428%, indicating a significant contribution of these factors to the data collected from 244 secondary and high school mathematics teachers. The remaining variance may be attributed to other influences not accounted for in the model. Though the total variance explained lacks a definitive threshold, this result aligns with common practices in social science research, where a level of 60% or more is generally considered acceptable [29]. As shown in Table 3, the six extracted factors contributed to the total variance as: 15.640% (factor 1), 13.284% (factor 2), 11.582% (factor 3), 10.740% (factor 4), 9.946% (factor 5), and 7.236% (factor 6). The figures demonstrate how each factor contributes to the explained variance, with factor 1 showing the highest contribution, underscoring its dominant role compared to the others.

Table 4. Results of component factor extraction

Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	3.284	15.640	15.640	3.284	15.640	15.640
2	2.790	13.284	28.924	2.790	13.284	28.924
3	2.432	11.582	40.506	2.432	11.582	40.506
4	2.255	10.740	51.246	2.255	10.740	51.246
5	2.089	9.946	61.192	2.089	9.946	61.192
6	1.519	7.236	68.428	1.519	7.236	68.428
7	0.764	3.636	72.064			
8	0.657	3.128	75.192			

Figure 3 illustrates the scree plot, where the sharp decline in eigenvalues supports the decision to retain 6 factors in the model. Upon examining the eigenvalue of the seventh factor, the result shows a value of 0.764, which is below the latent criterion threshold of 1.0, making it ineligible for retention in the analysis [25]. Although some argue that factors with eigenvalues close to 1.0 may still be considered, the consistency of the assessment criteria confirms that retaining six factors is the most methodologically sound choice, ensuring the rigor of the analysis. Additionally, this finding suggests a direction for future research, encouraging further exploration of these factors' real-world impact in educational settings.

Table 5 presents the factor loadings, with loading values ranging from 0.729 to 0.881. For samples of 200 or more, loadings of 0.40 or more are considered significant, so all observed variables are retained in the model [25]. In addition, Table 5 also confirms that all six factors meet the desired criteria, with at least three observed variables on each factor having loadings greater than 0.40, ensuring the stability of the model.

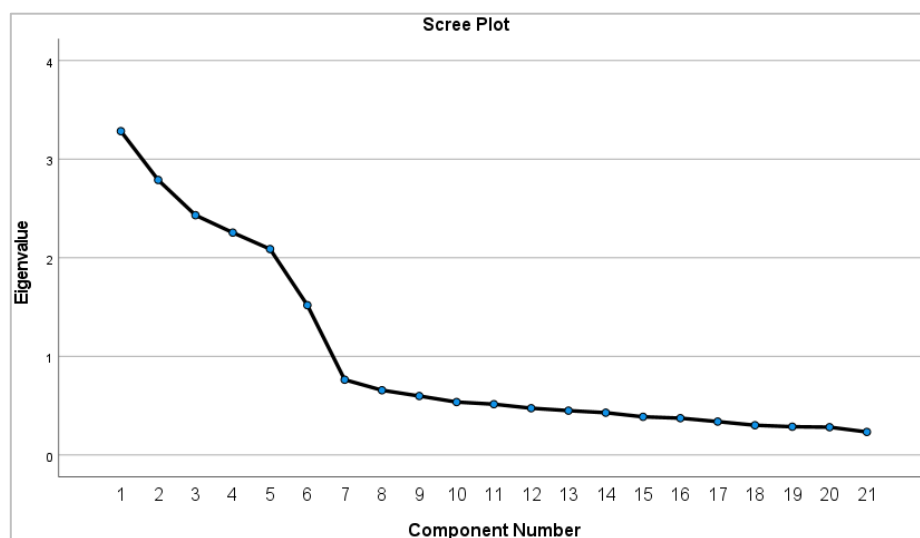


Figure 3. Scree plot

Table 6 presents the final results of the EFA, including the factor names, Cronbach's alpha coefficients, and factor loadings for each observed variable. The results confirm that the scale reliability for each factor meets the acceptable threshold as recommended by Hair *et al.* [25], with a cut-off value of 0.7. Factor 1, "facilities and teaching support," represents the availability and level of support from infrastructure

and resources for implementing PjBL. Factor 2, “capacity to organize PjBL,” reflects teachers’ ability to plan, coordinate, and implement PjBL effectively. Factor 3, “perception of PjBL,” refers to teachers’ understanding, perceptions, and attitudes toward this instructional method. Factor 4, “readiness for PjBL,” captures the level of preparation, initiative, and motivation of both teachers and students when engaging in PjBL activities. Factor 5, “teachers’ confidence in applying PjBL,” reflects teachers’ self-efficacy and the perceived impact of PjBL on students’ concentration, engagement, group work ability, and skill development. Finally, factor 6, “students’ characteristics,” encompasses students’ mathematical ability, communication and collaboration skills, and learning motivation. These results indicate that the extracted factors are meaningful and align well with the research model, confirming their relevance in explaining students’ engagement, learning interest, teamwork skills, and overall skill development within the context of PjBL. Thus, the results of the EFA identified six main factors, contributing to a clear and well-founded answer to RQ1.

Table 5. Rotated component matrix

Variable	Component					
	1	2	3	4	5	6
Q22	0.838					
Q23	0.814					
Q21	0.804					
Q24	0.783					
Q17	0.722					
Q1		0.843				
Q6		0.840				
Q5		0.818				
Q4		0.788				
Q3			0.881			
Q7			0.864			
Q2			0.807			
Q9				0.868		
Q14				0.834		
Q15				0.781		
Q10					0.858	
Q8					0.824	
Q11					0.777	
Q12						0.836
Q13						0.818
Q16						0.729

Table 6. Final results for EFA

Item	Factor	Loading
Factor 1. Facilities and teaching support (Cronbach’s alpha $\alpha=0.852$)		
Q22 The equipment, tools, and applications are in good working condition.		0.838
Q23 I can receive assistance from the service provider if I encounter issues with the equipment, tools, or applications.		0.814
Q21 I am provided with sufficient equipment, tools, and applications for project-based teaching.		0.804
Q24 The learning space is well-designed to support group work and the implementation of mathematical projects.		0.783
Q17 I receive policies and guidelines from the school and government that effectively support the implementation of PjBL.		0.722
Factor 2. Capacity to organize PjBL (Cronbach’s alpha $\alpha=0.841$)		
Q1 I understand how to integrate mathematics content into practical and interdisciplinary projects.		0.843
Q6 I am able to design criteria, tools, and assessments for the process and products of PjBL.		0.840
Q5 I am able to plan, organize, and coordinate student groups.		0.818
Q4 I can approach PjBL in a variety of ways.		0.788
Factor 3. Perception of PjBL (Cronbach’s alpha $\alpha=0.814$)		
Q3 I recognize that PjBL is more effective than traditional methods.		0.881
Q7 I believe that PjBL is an effective method for enhancing student learning outcomes.		0.864
Q2 I recognize the process of PjBL, including planning, implementation, and evaluation.		0.807
Factor 4. Readiness for PjBL (Cronbach’s alpha $\alpha=0.783$)		
Q9 I feel prepared to apply PjBL.		0.868
Q14 Students are confident and willing to work in groups when engaging in mathematical projects.		0.834
Q15 Most students remain focused while working on mathematical projects.		0.781
Factor 5. Teachers’ confidence in applying PjBL ($\alpha=0.765$)		
Q10 I believe that implementing PjBL helps students develop essential 21st-century skills such as critical thinking, communication, and collaboration.		0.858
Q8 I am enthusiastic about implementing mathematical projects in the classroom.		0.824
Q11 I am confident in designing and organizing PjBL activities.		0.777
Factor 6. Students’ characteristics ($\alpha=0.718$)		
Q12 Students with a strong understanding of mathematical concepts perform well in mathematical projects.		0.836
Q13 Students with good communication and collaboration skills excel in mathematical projects.		0.818
Q16 Students are enthusiastic and proactive in participating in mathematical projects to enhance their academic performance.		0.729

4.1.3. Confirmatory factor analysis

After identifying six latent factors from the EFA results, CFA was subsequently conducted to examine the measurement model's reliability and validity, aiming to address the second research question. As shown in Table 7, the reliability and validity of the scales employed in the CFA were evaluated. Each construct demonstrated a Cronbach's alpha above the accepted cutoff of 0.7, thereby confirming satisfactory internal consistency. The CR for all factors is ≥ 0.7 , indicating strong structural reliability. The AVE for most factors is ≥ 0.5 , demonstrating good convergent validity, meaning that the observed variables effectively represent their respective latent constructs. However, the "students' characteristics" factor has an AVE of 0.481, which is slightly below the 0.5 threshold. According to Hair *et al.* [31], when CR is sufficiently high (≥ 0.7) but AVE is slightly lower (< 0.5 , but > 0.4), the factor can still be retained because its overall reliability remains strong. Based on this criterion, the measurement model is considered reliable and acceptable.

Table 8 summarizes the fit indices of the CFA model. The results indicate that CMIN/DF=1.264, which meets the excellent fit criterion. Similarly, GFI=0.924 demonstrates an acceptable level of model fit. The indices AGFI=0.9 and NFI=0.887 fall within the acceptable range, reflecting the model's relative fit. Additionally, CFI=0.973, which exceeds the 0.95 threshold, confirming an excellent fit. Furthermore, RMSEA=0.033, which is below 0.05, indicates that the model exhibits a good fit. Finally, PCLOSE=0.989, significantly higher than the threshold value, confirms the very strong fit of the model.

Table 7. Cronbach's alpha, construct reliability, and AVE of the six factors

Factor	Items	Cronbach alpha	CR	AVE
Facilities and teaching support	5	0.852	0.855	0.542
Capacity to organize PjBL	4	0.841	0.844	0.576
Perception of PjBL	3	0.814	0.817	0.6
Readiness for PjBL	3	0.783	0.789	0.56
Teachers' confidence in applying PjBL	3	0.765	0.775	0.539
Students' characteristics	3	0.718	0.731	0.481

Table 8. Goodness of fit index of CFA model

No	Measure	Estimate	Threshold	Interpretation
1	CMIN/D	1.264	< 3	Excellent
2	GFI	0.924	$\geq .90$	Good
3	AGFI	0.9	$\geq .90$	Acceptable
4	NFI	0.887	$\geq .80$	Acceptable
5	CFI	0.973	$\geq .95$	Excellent
6	RMSEA	0.033	$\leq .05$	Good
7	PCLOSE	0.989	$\geq .05$	Excellent

Factor loading reflects the extent to which an observed variable represents a latent factor. A standardized factor loading should be ≥ 0.5 to be acceptable and ≥ 0.7 to be considered good [25]. Figure 4 shows that most factor loadings fall within the range of 0.69–1.00, ensuring strong convergent validity of the model. However, some variables have slightly lower coefficients (e.g., Q14=0.69, Q15=0.69), yet remain within the acceptable range. The curved arrows in the figure represent the correlations between factors. If a correlation coefficient ≥ 0.85 , it may indicate a multicollinearity issue between factors [32]. In this case, the correlation coefficients range from 0.00 to 0.10, confirming that the factors are well discriminated and that no multicollinearity issues exist. The test indices indicate that the measurement model achieves good reliability and validity, thereby confirming that RQ2 has been satisfactorily and scientifically addressed.

4.2. Discussion

4.2.1. Latent constructs influencing the adoption of project-based learning pedagogies (RQ1)

The results of the EFA revealed the extraction of 6 distinct factors, accounting for 68.428% of the total explained variance. This provides evidence of a well-defined, interpretable, and robust factor structure. The six primary factors influencing the organization of PjBL in mathematics education include: i) facilities and teaching support; ii) capacity to organize PjBL; iii) perception of PjBL; iv) readiness for PjBL; v) teachers' confidence in applying PjBL; and vi) students' characteristics.

The factor of facilities and teaching support plays an integral part in the effective implementation of PjBL. This finding aligns with the study in Nguyen *et al.* [1] which demonstrated that physical conditions and technological support significantly impact students' academic performance in PjBL environments. Supporting evidence from several researchers [20], [22], [23] further emphasizes that the availability of digital tools and appropriate infrastructure, such as smartphones, augmented reality software, and online platforms, can enhance students' spatial visualization, intuitive reasoning, and engagement in PjBL settings.

Collectively, these results underscore the significance of technological readiness and teacher training in sustaining the quality of mathematics instruction through PjBL.

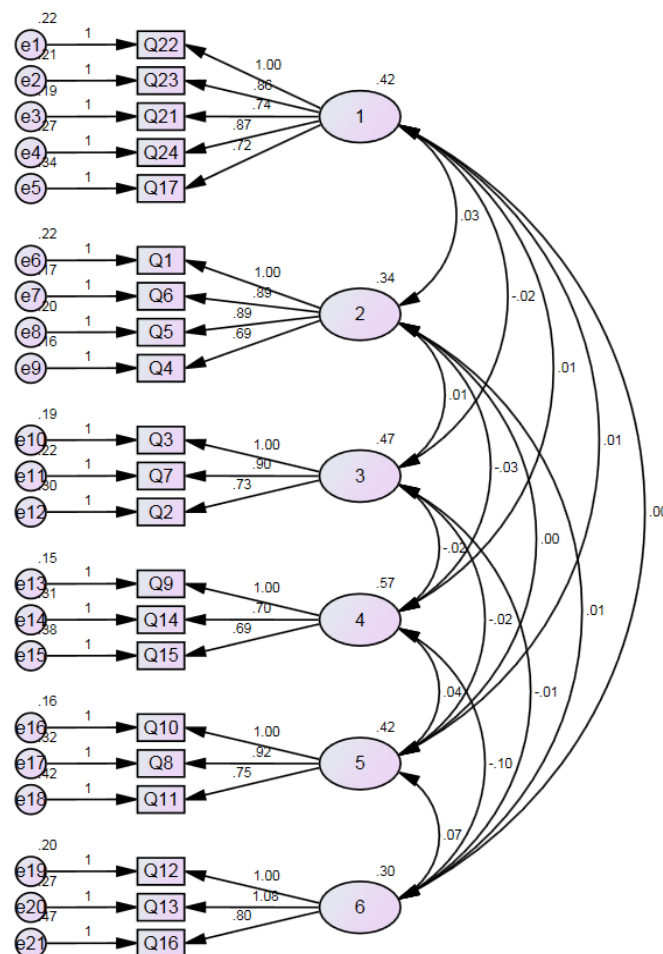


Figure 4. Model of six factors affecting the organization of PjBL in mathematics (note: factors numbered from 1 to 6 correspond to the groups of observed variables presented in Table 5)

The factor capacity to organize PjBL reflects teachers' professional capacity to design, implement, and assess PjBL activities. This result is in line with the findings of Tarasenkova *et al.* [10], which indicates that teachers' organizational competence is a determining factor in the success of PjBL in mathematics education. Furthermore, the study reported in Supriadi *et al.* [24] demonstrates that when project-based activities are systematically guided and tightly aligned with instructional objectives, they not only enhance student engagement but also foster deeper conceptual understanding. These findings collectively underscore the pivotal role of teachers' organizational competence in the effective implementation of PjBL.

The factor perceptions of PjBL pertains to teachers' understanding of the nature, benefits, and practical implementation of PjBL. This finding is consistent with the study in Nguyen *et al.* [1] which indicates that teachers with a clear perception of PjBL are more likely to adopt the method frequently and effectively. Moreover, Viro *et al.* [2] emphasizes that teachers who possess a deep understanding of the essence of PjBL are often better equipped to overcome implementation barriers and meaningfully integrate the approach into mathematics instruction.

The factor readiness for PjBL reflects the extent of teachers' preparation, both professionally and psychologically, for enacting PjBL in actual teaching practice. This study affirms that readiness constitutes a prerequisite for the sustainable and effective application of PjBL. Supporting this assertion, Viro *et al.* [2] reports that many teachers express a lack of readiness due to insufficient training, time constraints, and inadequate pedagogical resources, all of which hinder the full-scale implementation of PjBL in mathematics classrooms.

The factor teachers' confidence in applying PjBL reflects the extent to which teachers feel in control when managing classrooms, guiding students, and assessing learning outcomes. This finding aligns with the study in Choi *et al.* [33] which demonstrates that teachers' confidence has a positive impact on instructional effectiveness and student engagement. Furthermore, Tarasenkova *et al.* [10] emphasizes that teachers with high levels of confidence in implementing PjBL tend to employ learner-centered strategies and exhibit stronger commitment to project-based teaching.

Finally, the factor students' characteristics highlights the critical role of learners' cognitive and socio-emotional capacities. Student collaboration, autonomy, and motivation are essential components for the successful implementation of PjBL, particularly within STEM-oriented learning environments where teamwork and problem-solving skills are central [5], [20]. In addition, the study by Ubuz and Aydinler [7] indicates that differences in cognitive styles, such as field dependence versus field independence, also influence how students engage in PjBL activities in mathematics, thereby shaping their attitudes and depth of conceptual understanding.

4.2.2. The reliability and validity of the identified factors for subsequent investigation (RQ2)

The CFA analysis confirmed a 6-factor structure, with all factor loadings exceeding the threshold of 0.5 and model fit indices meeting established standards (e.g., RMSEA=0.033<0.05, CFI=0.973>0.95, GFI=0.924>0.9). These values indicate an excellent model fit, thereby affirming the construct validity and internal reliability of the measurement scale [25]. This approach aligns with prior studies that have employed both EFA and CFA to develop validated measurement instruments in mathematics education [26].

Moreover, the validated model can be regarded as a reliable and context-appropriate instrument for assessing teachers' readiness and the enabling conditions for implementing PjBL in practice. Theoretically, this study contributes by establishing an empirically grounded framework for measuring constructs related to PjBL. Practically, it offers valuable insights for designing targeted educational interventions and informing policy improvements, particularly in the context of Vietnam, where empirically validated PjBL models remain limited.

These findings are in agreement with earlier studies on PjBL, particularly within the context of mathematics education. However, several distinguishing features underscore its contribution. First, whereas most previous studies tend to focus on isolated factors, such as teacher competence, confidence, or infrastructural conditions, this study developed a comprehensive model encompassing six interrelated factors that collectively influence the implementation of PjBL. Second, the study systematically validated the reliability and construct validity of these factors using CFA, an approach that remains underutilized in mathematics education research in Vietnam. Third, the study adopts a broader scope by collecting data from teachers across multiple educational levels (lower and upper secondary), thereby offering a clearer depiction of how PjBL is currently implemented in mathematics education.

5. CONCLUSION

This study identified six key factors influencing the implementation of PjBL in mathematics education: i) facilities and teaching support; ii) capacity to organize PjBL; iii) perception of PjBL; iv) readiness for PjBL; v) teachers' confidence in applying PjBL; and vi) students' characteristics. The results from both EFA and CFA confirmed the robustness and reliability of this 6-factor model. These findings support the theoretical framework with empirical evidence for the multidimensionality of PjBL and the necessary conditions for its effective implementation.

The study also offers practical implications for various stakeholders. Teachers may benefit from targeted professional development programs in terms of enhancing their competencies and confidence in facilitating PjBL. In addition, educational institutions are suggested investing in infrastructure and pedagogical training to promote project-based teaching practices. Policymakers may leverage these findings to design strategic interventions that support the adoption and sustainability of PjBL in mathematics instruction.

Despite its contributions, the study has some inherent limitations. The survey sample was drawn from a specific geographic area, which may restrict the applicability of the results to broader populations. Future research should expand the sampling scope and utilize more sophisticated statistical methods, such as multiple regression or structural equation modeling, to explore the causal relationships between the identified factors and the effectiveness of PjBL implementation.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author [HTMN], upon reasonable request.

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